Washington State Department of Transportation

U.S. 101 MP 98.47 Unnamed Tributary to West Fork Hoquiam River (WDFW ID 993702): Preliminary Hydraulic Design Report

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1 Introduction

To comply with United States et al. vs. Washington et al. No. C70-9213 Subproceeding No. 01-1 dated March 29, 2013 (a federal permanent injunction requiring the State of Washington to correct fish barriers in Water Resource Inventory Areas [WRIAs] 1–23), the Washington State Department of Transportation (WSDOT) is proposing a project to provide fish passage at the United States Highway 101 (U.S. 101) crossing of the unnamed tributary to the West Fork Hoquiam River at Mile Post (MP) 98.47. This existing structure on U.S. 101 has been identified as a fish barrier by the Washington Department of Fish and Wildlife (WDFW) and WSDOT Environmental Services Office (ESO) (site identifier [ID] 993702) and has an estimated 3,401 linear feet (LF) of habitat gain (WDFW 2021).

Per the injunction, and in order of preference, fish passage should be achieved by (1) avoiding the necessity for the roadway to cross the stream, (2) use of a full-span bridge, or (3) use of the stream simulation methodology. WSDOT evaluated the crossing using the stream simulation methodology.

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The crossing is located in Grays Harbor County 9.5 miles north of Hoquiam, Washington, in WRIA 22. The highway runs in a north–south direction at this location and is about 60 feet (ft) from the confluence with the West Fork Hoquiam River. The West Fork Hoquiam River generally flows from north to south beginning upstream of the U.S. 101 crossing. The unnamed tributary (UNT) generally flows from northeast to southwest beginning approximately 4,000 feet upstream of the U.S. 101 crossing (see Figure 1 for the vicinity map).

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The proposed project will replace the existing structure, an 80-foot long, and 3-foot concrete circular culvert with a concrete box culvert with a hydraulic opening of 13 feet. The proposed structure is designed to meet the requirements of the federal injunction using the stream simulation design criteria as described in the 2013 WDFW *Water Crossing Design Guidelines* (WCDG) (Barnard et al. 2013). This design also follows the WSDOT *Hydraulics Manual* (WSDOT 2019) with supplemental analyses as noted.

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A draft Preliminary Hydraulic Design (PHD) report was prepared in 2020 by WSDOT and HDR Engineering, Inc. under Agreement Number Y-12374 between HDR and WSDOT Environmental Services Office. WSDOT received review comments on the draft PHD report from WDFW and the Quinault Indian Nation (QIN). As part of Kiewit's Coastal-29 Team of the US 101/SR 109 Grays Harbor/Jefferson/Clallam, Remove Fish Barriers Project under a Progressive Design-Build (PDB) contract between Kiewit and WSDOT, Kleinschmidt Associates (KA) reviewed the draft PHD report, updated the hydraulic modeling and design, addressed WDFW and Tribe comments, and prepared this Draft Final PHD report using material in the draft PHD report as a starting point. Responses to WDFW and Tribe comments are included in Appendix J. While HDR's original field observations and measurements, and selected figures have been retained in this report, all writing and analyses in the draft PHD report have been reviewed, edited, and updated where determined necessary.

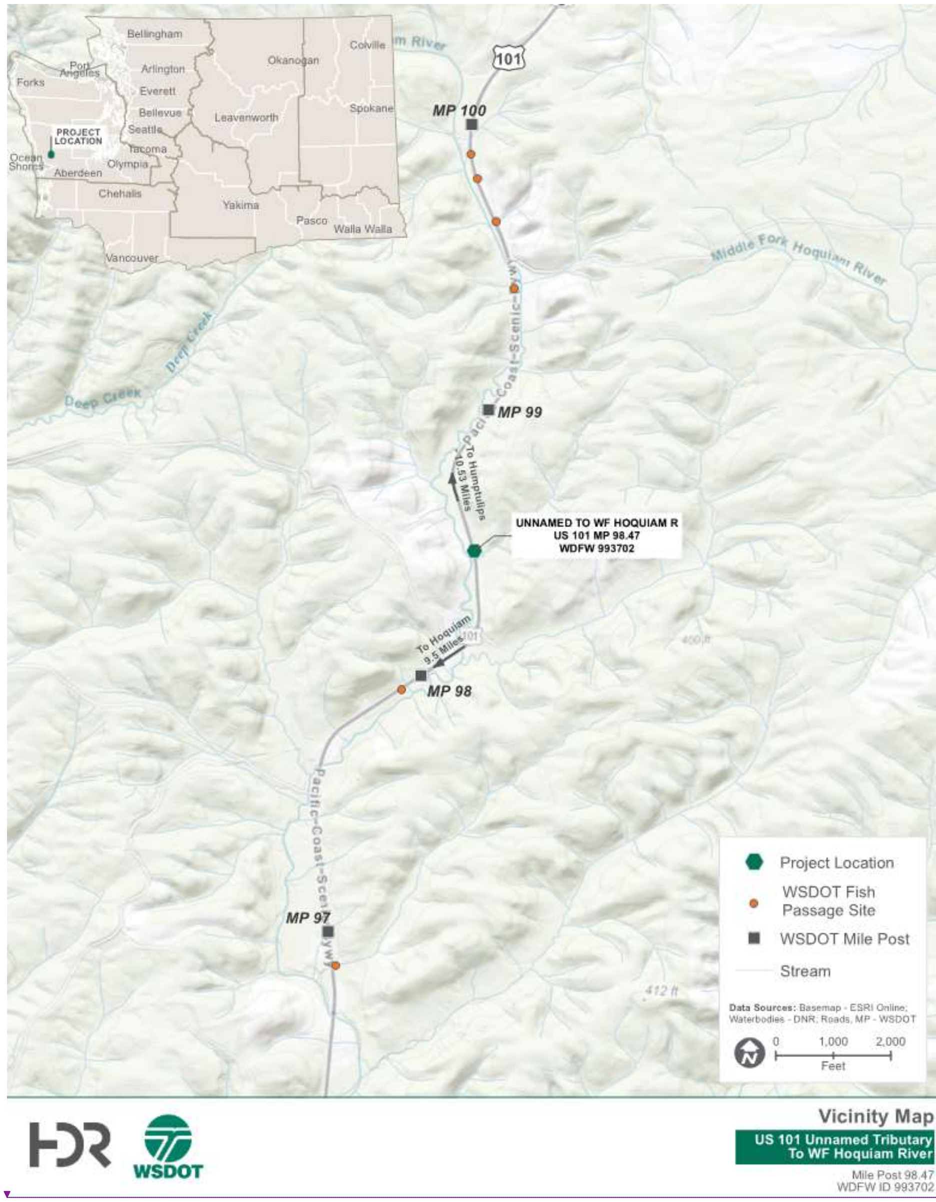

Figure 1: Vicinity map

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2 Watershed and Site Assessment

The existing site was assessed in terms of watershed, land cover, geology, floodplains, fish presence, observations, wildlife, and geomorphology. This was performed using desktop research including aerial photos; resources such as the United States Geological Survey (USGS), Federal Emergency Management Agency (FEMA), and WDFW; past records like observation, and fish passage evaluation; and site visits.

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2.1 Watershed and Land Cover

The project stream is located in the southern foothills of the Olympic Mountains, approximately 9.5 miles north of Hoquiam, WA, and as a tributary of the West Fork Hoquiam River, drains to the west under U.S. 101. The watershed is generally forested, and the perimeter of the basin is encircled by existing logging roads. Light detecting and ranging (LiDAR) data indicates the presence of minor drainages, but no other major tributaries are present within the basin. Elevations in the basin vary from approximately 185 to 385 feet with a mean basin elevation of 320 feet and a mean basin slope of about 11.5 percent. Downstream of the crossing, the stream flows approximately 30 feet before joining the West Fork Hoquiam River as a left bank tributary. The West Fork Hoquiam River is joined by several additional tributaries before joining the East Fork Hoquiam River.

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Land cover for this basin consists of primarily forest and scrub/shrub land. The 2016 National Land Cover Database (NLCD) map shows land cover to be mostly evergreen forest with dispersed regions of shrub, deciduous forest, and low-intensity development (Figure 2; Table 1). The Grays Harbor County Assessor's Office web mapping database indicates the stream flows through a parcel owned by a timber company. The entire basin has been logged at one time or another and is encircled with logging roads. Historic aerial imagery on Google Earth indicates that nearly all of the drainage was clearcut on the north side of the channel in the early 2000s, leaving a narrow riparian buffer strip. Future timber harvest is expected to follow Washington's Forest Practices Habitat Conservation Plan requirements involving wider buffer strips than was typical prior to 2005.

Table 1: Recent major land cover composition upstream of culvert

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Land Cover Class	Basin Coverage (Percentage)
Evergreen forest	67
Deciduous forest	28.5
Low-intensity development	4.5

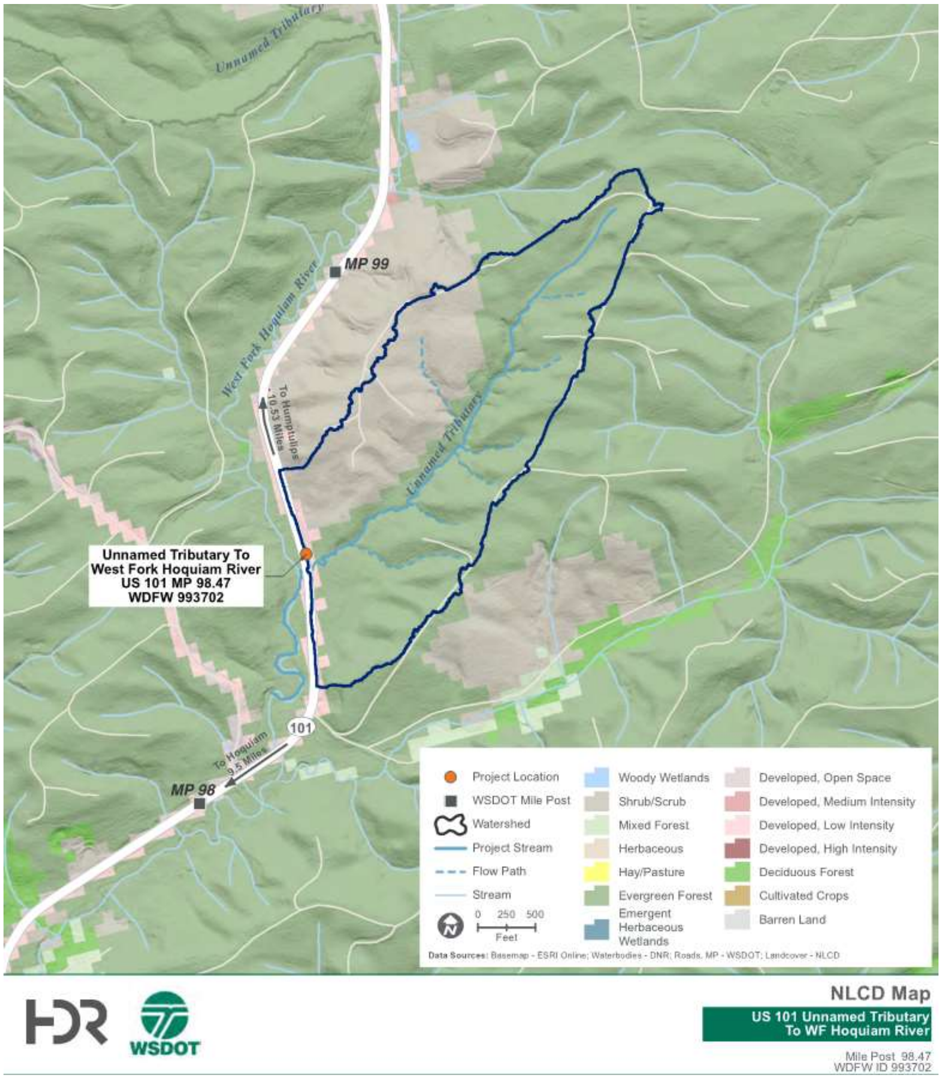

Figure 2: Land cover map (NLCD 2016). Approximate catchment area upstream of the culvert is depicted

2.2 Geology and Soils

The drainage basin is underlain entirely by Pleistocene Age, alpine glacial outwash, dated as younger pre-Wisconsinan in age as mapped at the 1:100,000 scale (Figure 3; Logan 2003; Washington Division of Geology and Earth Resources 2016; Washington State Department of Natural Resources (DNR) Geologic Information Portal. Logan (2003) describes this unit as consisting of sand and gravel, composed of sandstone and basalt derived from the core of the Olympic Mountains. Clasts comprising the deposit are generally moderately to well-rounded with characteristic red-orange weathering rinds. The grain size distribution (GSD) of the material is characteristically poorly to moderately sorted and the material is weathered to depths exceeding 12 feet.

No indicators of landslide activity were observed during the 7/13/2021 field visit. A boundary search conducted on August 2021 of the DNR landslide inventories and hazards (Washington Geological Survey, 2020a, 2020b) identified no landslide studies or landslide hazards within the watershed. The watershed's steep hillslopes are dominated by highly to moderately erodible Copalis and Le Bar soil types (Figure 4; NRCS 2012). The soil characterization and geological description suggest a source and potential supply of sands and gravels to the project stream.

According to a recent geotechnical boring on the east side of the US 101 shoulder, there is dense silty, sand with gravel at depth (below 159 ft Above Sea Level (ASL)), and a sandy elastic silt from elevation 159-166 feet ASL. From 166-172.5 feet ASL, were silty sands and gravels, topped with 7.3 feet of fill and asphalt. (WSDOT 2020). Our interpretation is that the project stream erodes its uplands composed solely of Pleistocene Alpine outwash and reworked alluvium.

2.3 Floodplains

The project is not within a regulatory Special Flood Hazard Area, which is the 1 percent or greater annual chance of flooding in any given year. The existing U.S. 101 culvert is located in Zone X (unshaded) based on FEMA Flood Insurance Rate Map (FIRM) 53027C0675D, effective date February 3, 2017 (Appendix A). An unshaded Zone X represents areas of minimal flood hazard from the principal source of flooding in the area and is determined to be outside the 0.2 percent annual chance floodplain. Maintenance records provided do not describe any historical flooding issues.

2.4 Site Description

The project stream is an unnamed left bank tributary to the West Fork Hoquiam River, which flows south towards Grays Harbor. The existing culvert was documented by WDFW to have an estimated 67 percent passability as controlled by slope and excessive velocities in the culvert, and is downstream of an estimated 3,400 feet of habitat (WDFW 2021). Habitat in the vicinity of the culvert and upstream appears to be primarily suitable for juvenile salmonids, and possibly adult resident salmonids, with an estimated 160 ft^2 of spawning habitat upstream. There are small patches of gravel present in hydraulically sheltered locations, but spawning habitat was not found within the project reach.

The structure has not been identified as a failing structure or with a status of chronic environmental deficiency. No maintenance problems have been noted by WSDOT for this culvert.

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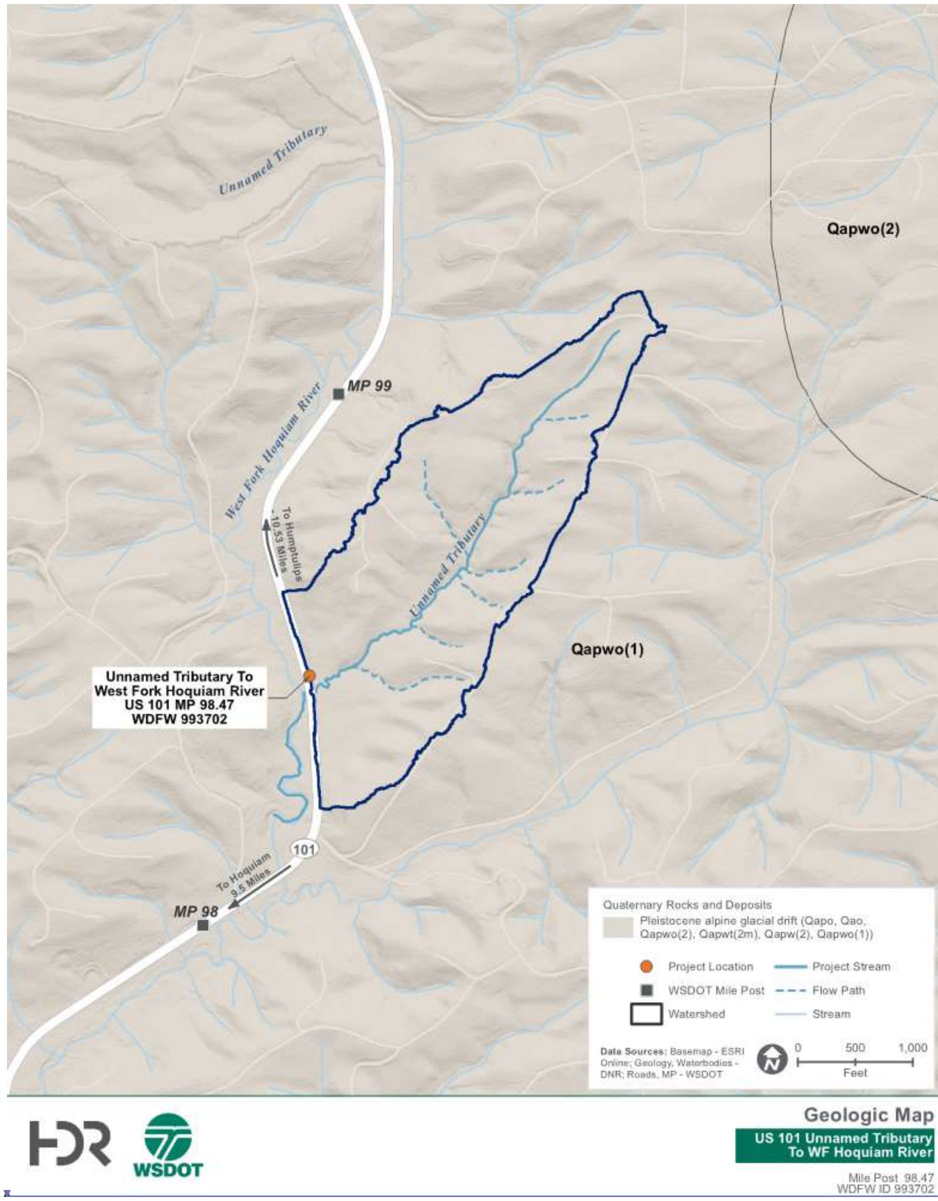

Figure 3: Geologic map. Approximate catchment area upstream of the culvert is depicted

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The online databases for the Statewide Washington Integrated Fish Distribution (SWIFD) (2020) and WDFW SalmonScape and Priority Habitats and Species (PHS) data (WDFW 2020a, 2020b) do not indicate documented fish use upstream of the culvert. Rainbow trout, the resident form of steelhead (*Oncorhynchus mykiss*), are presumed present (SWIFD 2020). The project crossing, however, is within approximately 30 feet of the West Fork Hoquiam River, which is documented to have Coho Salmon (*O. kisutch*), steelhead, and coastal Cutthroat Trout (*O. clarkii clarkii*) (SWIFD 2020; WDFW 2020a, 2020b; StreamNet 2020), and are assumed to be able to use habitat upstream of the culvert (WDFW 2021; Table 2).

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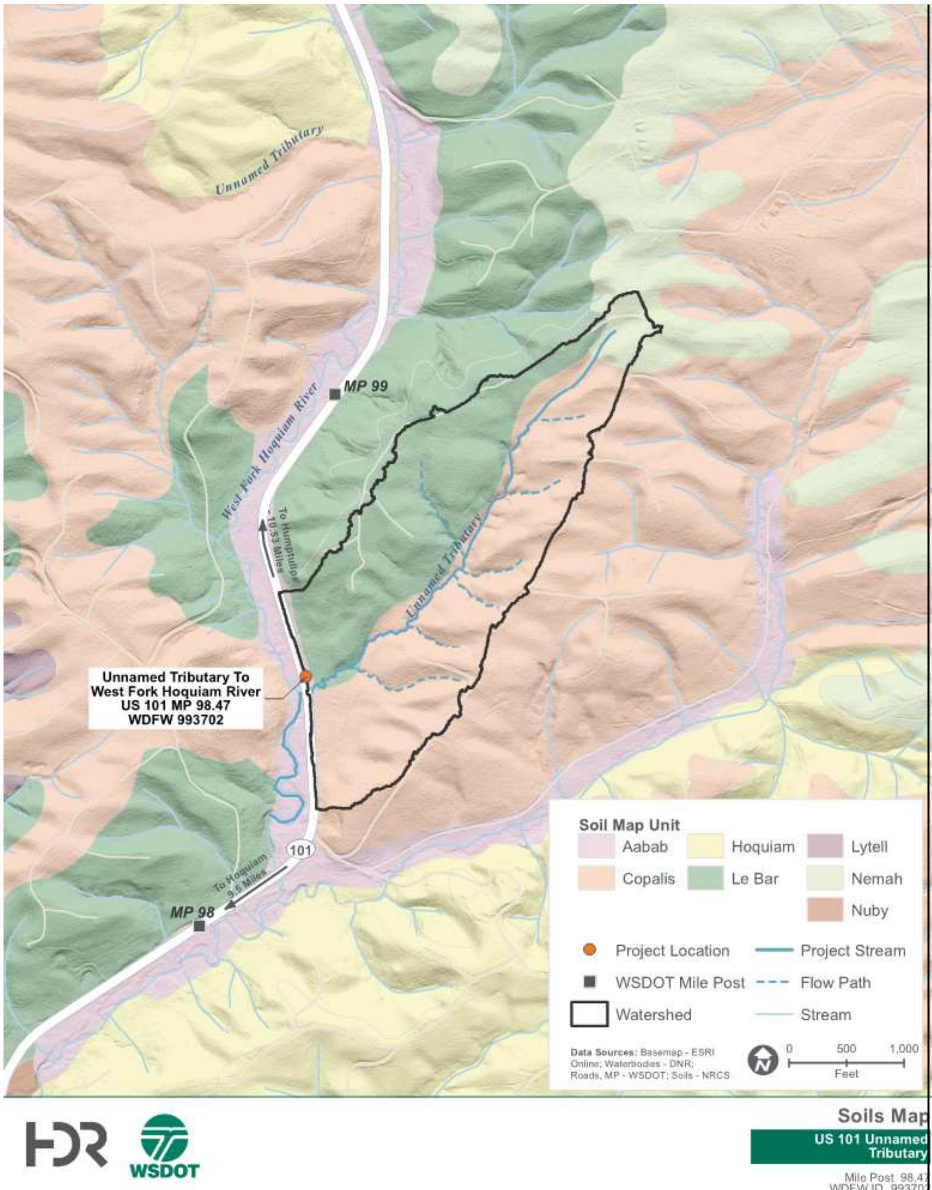

Figure 4: Soils map. Approximate catchment area upstream of the culvert is depicted

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2.5 Fish Presence in the Project Area

The online databases for the Statewide Washington Integrated Fish Distribution (SWIFD) (2020) and WDFW SalmonScape and Priority Habitats and Species (PHS) data (WDFW 2020a, 2020b) do not indicate documented fish use upstream of the culvert. Rainbow trout, the resident form of steelhead (*Oncorhynchus mykiss*), are presumed present (SWIFD 2020). The project crossing, however, is within approximately 30 feet of the West Fork Hoquiam River, which is documented to have Coho Salmon (*O. kisutch*), steelhead, and coastal Cutthroat Trout (*O. clarkii clarkii*) (SWIFD 2020; WDFW 2020a, 2020b; StreamNet 2020), and are assumed to be able to use habitat upstream of the culvert (WDFW 2021; Table 2).

Coho Salmon spend their first year rearing in fresh water and can disperse throughout tributaries and off-channel habitats. Suitable coho rearing habitat is present in the project reach and Coho overwintering and rearing is presumed.

Steelhead that inhabit the watershed are part of the Southwest Washington distinct population segment (DPS) and are not currently listed under the Endangered Species Act (ESA). Rearing and overwintering juvenile steelhead may potentially disperse upstream into the unnamed tributary by the project crossing.

Coastal Cutthroat Trout are widespread throughout small streams in Washington, prefer the uppermost portions of these streams, and can be anadromous and rear in streams for 2 to 3 years or be resident and remain entirely in fresh water (Wydoski and Whitney 2003). It is possible that Cutthroat Trout may also use habitat upstream of the culvert.

A single small salmonid fish (~2 inches) was observed near the culvert inlet, upstream of U.S. 101 during a field visit performed by HDR staff on May 14, 2020.

Table 2: Native fish species potentially present within the project area

Species	Presence (presumed, modeled, or documented)	Data source	ESA listing[a]
Coho Salmon (*Oncorhynchus kisutch*)	Presumed (documented in West Fork Hoquiam River)	SWIFD 2020, WDFW 2020a, WDFW 2020b	Not warranted
Southwest Washington DPS[b] steelhead (*Oncorhynchus mykiss*)	Presumed (documented in West Fork Hoquiam River)	SWIFD 2020, WDFW 2020a, WDFW 2020b	Not warranted
Coastal Cutthroat (*Oncorhynchus clarkii clarkii*)	Presumed (documented in West Fork Hoquiam River)	SWIFD 2020, WDFW 2020b	Not warranted

a. ESA = Endangered Species Act.
b. DPS = distinct population segment.

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Floodplains¶
The project is not within a regulatory Special Flood Hazard Area, which is the 1 percent or greater annual chance of flooding in any given year. The existing U.S. 101 culvert is located in Zone X (unshaded) based on FEMA Flood Insurance Rate Map (FIRM) 53027C0675D, effective date February 3, 2017 (Appendix A). An unshaded Zone X represents areas of minimal flood hazard from the principal source of flooding in the area and is determined to be outside the 0.2 percent annual chance floodplain. Maintenance records provided do not describe any historical flooding issues. ¶
Site Description¶
The project stream is an unnamed left bank tributary to the West Fork Hoquiam River, which flows south towards Grays Harbor. The existing culvert was documented by WDFW to have an estimated 67 percent passability as controlled by slope and excessive velocities in the culvert, and is downstream of an estimated 3,400 feet of habitat (WDFW 2021). Habitat in the vicinity of the culvert and upstream appears to be primarily suitable for juvenile salmonids, and possibly adult resident salmonids, with an estimated 160 ft^2 of spawning habitat upstream. There are small patches of gravel present in hydraulically sheltered locations, but spawning habitat was not found within the project reach.¶
The structure has not been identified as a failing structure or with a status of chronic environmental deficiency. No maintenance problems have been noted by WSDOT for this culvert. ¶

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Floodplains¶
The project is not within a regulatory Special Flood Hazard Area, which is the 1 percent or greater annual chance of flooding in any given year. The existing U.S. 101 culvert is located in Zone X (unshaded) based on FEMA Flood Insurance Rate Map (FIRM) 53027C0675D, effective date February 3, 2017 (Appendix A). An unshaded Zone X represents areas of minimal flood hazard from the principal source of flooding in the area and is determined to be outside the 0.2 percent annual chance ... [3]

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2.6 Wildlife Connectivity

The one mile segment that the culvert lies within is ranked Medium priority for Ecological Stewardship and Low priority for Wildlife-related Safety. Adjacent segments to the north and south ranked Low. WSDOT has determined that in order to be eligible for a habitat connectivity analysis, fish barrier correction projects must fall in or adjacent to a high priority road segment, or a project team member can request the analysis. No changes to design appear to be needed to accommodate wildlife crossing.

2.7 Site Assessment

A site assessment was performed of fish habitat conditions, hydraulic and geomorphic characteristics, and the culvert based on field visits, WDFW's barrier inventory report (WDFW 2021), and a WSDOT survey. An initial visit occurred in 2020, with subsequent visits postponed until 2021 after the Covid-19 pandemic had begun to subside.

2.7.1 *Data Collection*

Site visits were performed on four occasions to collect data and observe conditions and characteristics influencing the hydraulic design:

- HDR visited the project site on May 14, 2020, to collect pertinent information to support development of an initial design, including bankfull width (BFW) measurements, and characterizations of instream fish habitat and floodplain conditions. Channel substrates, large wood accumulations and floodplain vegetation were characterized.
- Kleinschmidt-R2 and Kiewit visited the site on June 1, 2021 to corroborate the initial data collection findings, review the representativeness of the BFW and channel substrate measurements, and identify additional data collection needs.
- Kleinschmidt-R2 and Kiewit visited the site on June 16, 2021 to collect a bulk substrate sample, measure the hydraulic effect of natural downstream in-channel flow obstructions as it would affect hydraulic modeling predictions, and measure the typical size of mobile wood pieces upstream of the culvert as they would affect the determination of minimum freeboard requirements.
- Kleinschmidt-R2 and NHC visited the site on July 13, 2021 to support an evaluation of the long term vertical stability of the channel.

Field reports are presented for each visit in Appendix B.

WSDOT also surveyed the site in March 2020. The survey extended approximately 200 feet upstream of the culvert, 100 feet downstream of the culvert, and a total roadway survey length of 1,500 feet. The reach surveyed comprises the project reach within which most data were collected, and observations made for use in developing the design. Survey information included break lines defining stream bank toes and tops and overbank areas along the channel. The data were used to generate hydraulic models and evaluate geomorphology during development of the hydraulic design.

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2.7.2 ***Existing Conditions***

2.7.2.1 Culvert

The existing structure is an 80 feet long, 36-inch diameter round concrete pipe with a gradient of approximately 1.7 percent (WDFW 2021). No local constraints, infrastructure, or obvious signs of maintenance activity were observed in the immediate vicinity of the project site during site visits. The culvert inlet invert is approximately 2 to 3 inches above the channel thalweg at a pool tail, whereas the culvert outlet is countersunk (Figure 5). The stream banks are approximately 2 feet tall and vertical near the culvert inlet, and approximately 2 to 3 feet tall near the outlet.

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Figure 5: Culvert inlet (left) and outlet (right)

2.7.2.2 Stream

The project stream enters the West Fork Hoquiam River (Figure 6) approximately 30 feet downstream of the culvert, at roughly a 90-degree angle. There is a log with rootwad situated at the confluence with the West Fork Hoquiam River that splits flows within the tributary channel as it enters the West Fork Hoquiam River (Figure 7).

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The West Fork Hoquiam River is a substantially larger channel than the project stream and backs water up to the culvert during high flow. The mainstem channel is shallow above the confluence and transitions to a deep pool downstream. The banks of the West Fork Hoquiam River are approximately 3 feet high and have mature trees growing on them; additionally, the left bank upstream in the West Fork Hoquiam River is composed of several logs. A large (36-inch diameter) fallen conifer spans the West Fork Hoquiam River at the confluence, and its rootwad has been undercut by a small side flow from the project tributary. The streambed material in the river is composed primarily of sand and small gravel.

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The project stream banks are approximately 1 foot high near the confluence. Bank materials are soft and silty and are overgrown with shrubs, ferns, and grass. No active bank erosion was observed in either the project stream channel or the mainstem during site visits. Some smaller trees roughly 3 inches in diameter are set back from the tributary by about 15 feet. The channel material is primarily silts and fines, with some gravel and sand present. Woody material was observed frequently in the channel. Upstream of the confluence by approximately 10 or 15 feet, a second woody material jam of sediment and woody material is lodged on several posts within the stream. At this upstream jam, the water surface drops between approximately 1-2 feet. The streambed material between the culvert and river is composed of primarily fine sand and silt.

Figure 6: West Fork Hoquiam River

Figure 7: Rootwad log in project stream

The channel bed material upstream of the culvert is primarily sand and silt with some larger gravels present as pockets. Banks consist of mud and silt with riparian vegetation of shrubs and ferns. Larger trees are set back from the channel by approximately 15 feet and their branches grow over the channel. There is a drop in the water surface profile of about 6 inches over a natural cross-channel log located approximately 25 feet upstream of the culvert inlet (Figure 8). Upstream of the log, the channel is abutted by a small floodplain. The banks are soft with organic litter and moss. The channel material in this reach is composed primarily of gravels and fines, and there is substantially more woody material in the channel than downstream of the culvert. Riparian vegetation includes shrubs with some trees along the channel margin. There are multiple locations upstream of the log weir where woody debris is racked in the channel and the stream flows over and under various sized logs (Figure 9). Stream banks are mostly vertical, up to 4 feet in height in places with live trees and other vegetation along the channel margins (Figure 10). There are several large diameter trees lying across the channel where the channel has widened and scoured locally.

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Figure 8: Natural log weir

Figure 9: Examples of embedded and channel spanning logs upstream of the culvert

Figure 10: Example of a vertical bank with vegetation

2.7.2.3 Floodplain

The channel downstream of the culvert flows within the floodplain of the West Fork Hoquiam River. The project stream appears to have little influence on overbank flows compared with the mainstem. Upstream of the culvert, the channel is not entrenched, where there is a defined bankfull channel with a narrow floodplain. The surface of the floodplain is irregular in morphology, not densely vegetated, and interspersed with fallen trees and woody debris.

2.7.3 ***Fish Habitat Character and Quality***

Upstream of the U.S. 101 crossing, the stream flows through a mixed forest composed primarily of alder (*Alnus rubra*), western hemlock (*Tsuga heterophylla*), and Douglas fir (*Pseudotsuga menziesii*). There is a dense shrub understory with native species including salmonberry (*Rubus spectabilis*), vine maple (*Acer circinatum*), salal (*Gaultheria shallon*), and sword fern (*Polystichum munitum*). The banks in the upstream reach next to the culvert inlet were topped by a dense shrub layer, then the understory becomes much more open upstream where the forest canopy is denser. The streambanks were generally low, with few incisions or undercuts.

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The mature forest and shrub cover provides shading, nutrient inputs, and some potential for local LWM recruitment. LWM is important in western Washington streams in that it provides cover for fish and contributes to stream complexity, which is beneficial to salmonids. There were five places where logs and woody material were present in the stream channel and banks, and a total of 14 key pieces of LWM. These logs ranged from 6 to 48 inches in diameter. Smaller woody material including small branches and twigs in the streambed was also prevalent throughout the reach. These logs and woody material provide instream habitat cover and complexity for use by juvenile salmonids for rearing and overwintering.

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Instream habitat within the project reach consists of predominantly shallow glides and riffles with fines and embedded gravel substrates, and limited pool habitat. Small scour pools form around flow obstructions. The paucity of pools and instream habitat complexity does not provide abundant rearing habitat, but juvenile Coho and possibly juvenile steelhead could still use the stream for some rearing and overwintering habitat, particularly during higher flows in the mainstem downstream.

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The downstream reach is a short, 30-foot-long reach between the culvert outlet and the confluence with the West Fork Hoquiam River. The riparian vegetation in this area is dominated by shrubs and forbs as part of the road prism for U.S. 101. At the West Fork Hoquiam River, there are some alders and a few fir trees along the left bank where the unnamed tributary confluence is located, and large cedars (*Thuja plicata*) on the opposite bank. The riparian corridor is constrained on the left bank of the stream because of its proximity to the highway. There is a dense shrub understory with native species including salmonberry (*Rubus spectabilis*), willows (*Salix spp.*), Devils club (*Oplopanax horridus*), sedges, and non-native species including Himalayan blackberry (*Rubus armeniacus*). The immature forest canopy provides little shading over the tributary. The shrub cover provides nutrient inputs, and some cover and shading along the banks.

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The substrate in the downstream reach is composed almost entirely of fines, small gravel, and organic material. This instream habitat is not suitable for spawning for salmonid species, but does provide some potential rearing and migratory habitat. There is little instream habitat complexity, and pools and cover are lacking in the downstream reach. There was one small scour pool at the confluence along the right bank where a log embedded in the bank was undercut. The lack of pools and instream habitat complexity does not provide good rearing habitat, but the project reach still provides some off-channel habitat from the West Fork Hoquiam River and migratory habitat as access to the tributary upstream.

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2.8 Geomorphology

Geomorphic information provided for this site includes selection of a reference reach, the basic geometry and cross sections of the channel, stability of the channel both vertically and laterally, and various habitat features.

2.8.1 *Reference Reach Selection*

The reach starting approximately 150 feet upstream of the culvert (Figure 11) was selected as most representative of the natural stream channel with the least anthropogenic influence. The reach downstream of the culvert was not considered a suitable reference because it experiences backwater from the West Fork Hoquiam River. The reference reach has an approximate average channel gradient of 2.2 percent. The reference reach was relied on primarily for measuring bankfull dimensions for informing the design of the hydraulic opening width and the cross-section morphology of the constructed channel outside of the replacement structure footprint. The reference reach morphology was not used to design cross-section shape and planform underneath the replacement structure because vegetation controlling bank stability cannot generally grow there.

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2.8.2 *Channel Geometry*

Channel planform upstream of the existing culvert is characterized by a single thread meandering channel with a distinct bankfull morphology and floodplain. The channel meanders through several sharp bends formed in conjunction with immovable large wood and the adjacent hillslope. LWM is present in the channel and on the channel banks. The short reach of channel between the culvert and West Fork Hoquiam River is narrower than upstream. Woody material pieces are present in the channel, but are smaller in size than in the upstream reach. Channel morphology is judged to be generally stable, consistent with Stage I of Schumm et al.'s (1984) Channel Evolution Model.

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Bankfull width (BFW) was measured with a tape at three locations in 2020, and determined at two other locations in 2021 based on surveyed cross-section profiles, upstream of the crossing within the reference reach (Figures 11 and 12; Table 3). The measured BFWs resulted in a design average BFW of 6.7 feet. As an independent check, the BFW estimate based on the WCDG regression equation for high-gradient, coarse-bedded streams in western Washington was 8.1 ft, based on the basin area and mean annual precipitation (see Section 3; Barnard et al. 2013). In addition, WSDOT also surveyed cross-sections at four other locations upstream of the culvert, above the influence of the West Fork Hoquiam River, as part of data collection for developing the hydraulic models (Figure 13). Station (STA) 2+15 was located within the reference reach. The cross-sections are characterized by vertical banks about 1.5 to 2.0 feet in height, a defined channel with a flat right floodplain, and a sloped left floodplain. Channel BFWs are around 8 feet or less. The width-to-depth ratio measured at STA 2+15 is approximately 4.5:1. The QIN visited the site after the 2020 BFW measurements were made, and measured different, larger

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widths. An average value of 9 feet was proposed. In subsequent discussions between WSDOT, QIN, and WDFW, a design value of BFW = 9.0 ft consistent with QIN measurements was selected (Table 3).

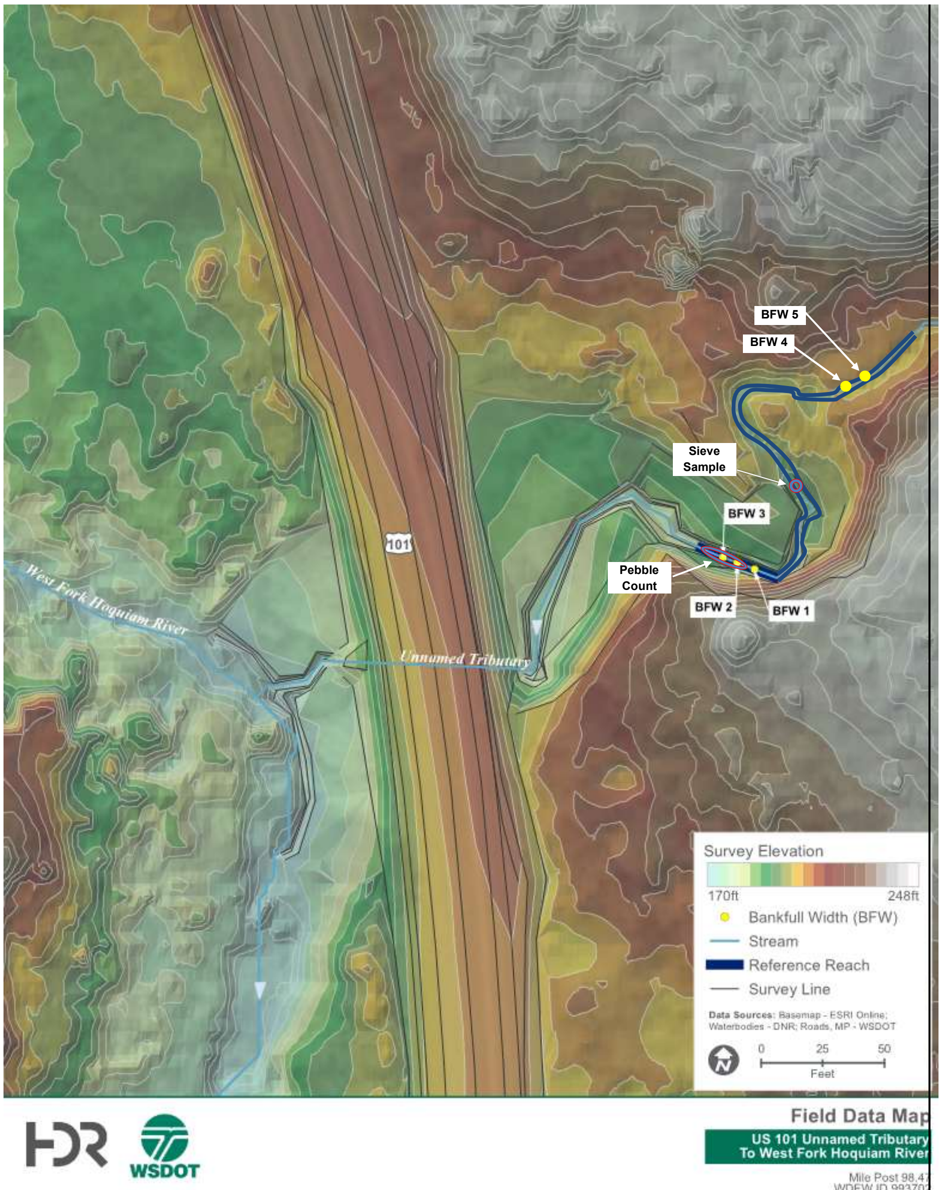

Figure 11: Reference reach and locations of BFW measurements and substrate sampling

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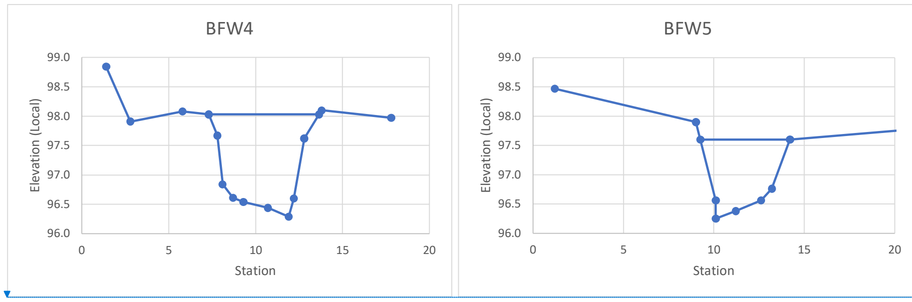

Figure 12: Cross-section profiles surveyed in 2021 for BFW determination

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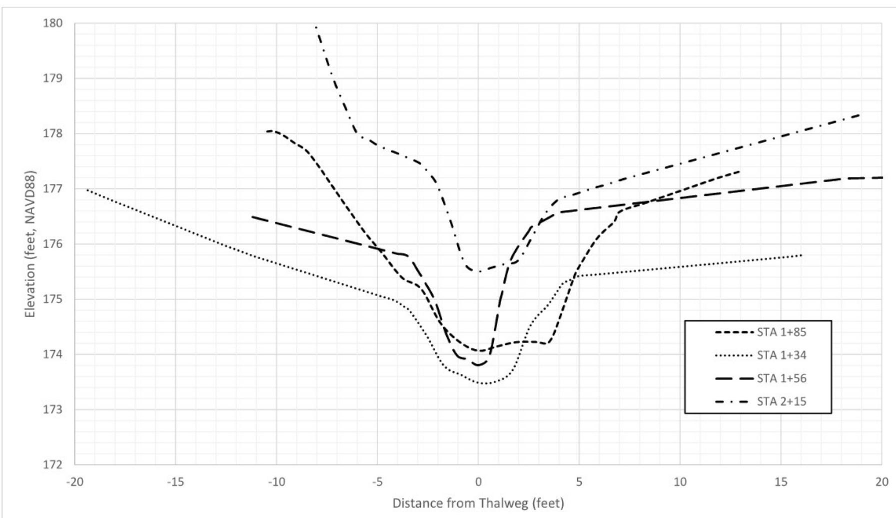

Figure 13: WSDOT's surveyed cross-section profiles upstream of the culvert

Table 3: Bankfull width (BFW) measurements

BFW #	Width (ft)	Included in Average	Concurrence notes
1	7.7	Yes	QIN Measured 9 ft
2	8.3	Yes	QIN Measured 10 ft
3	6.1	Yes	QIN – Do not include, not representative
4	6.4	Yes	New measurement based on cross-section profile
5	5.0	Yes	New measurement based on cross-section profile
Average	**6.7**		**BFW=9 ft accepted by Co-Managers, June 9, 2021**

2.8.3 *Sediment*

During the May 2020 site visit, a single Wolman pebble count was performed approximately 150 feet upstream of the culvert inlet within the reference reach. Additional pebble counts were not performed at the time based on reasoning that the existing streambed material grain size distribution was clearly finer than WSDOT's Standard Streambed Sediment, which was anticipated to be specified in the design. Upon further review, a sieve sample was subsequently collected from a distinct gravel deposit in June 2021, to provide an indication of the coarsest sediments that could be transported to the replacement structure. The locations of the sampling are indicated in Figure 11. The grain size distribution characteristics are summarized in Table 4. The largest sediment size in this reach observed was 3.5 inches (median axis diameter).

Table 4: Sediment properties upstream of project crossing

Particle size	Pebble Count Diameter (in)	Pebble Count Diameter (mm)	Sieve Sample Diameter (in)	Sieve Sample Diameter (mm)
D_{16}	0.1	3	0.1	3
D_{50}	0.2	5	1.0	26
D_{84}	0.4	10	1.9	47
D_{95}	0.8	20	2.3	59
D_{max}	3.5	89	-	-

2.8.4 *Vertical Channel Stability*

Vertical channel stability was assessed considering land use, longitudinal channel elevation profiles of the project stream and West Fork Hoquiam River, topographic models, and field observations on July 13, 2021. It may be assumed that historical land use in the watershed caused changes in sediment supply, wood loading, and runoff to a greater extent than what may be expected in the future, for several reasons. First, there is a low potential of landslides or debris flow type sediment delivery in the watershed (Section 2.2). Historical logging within the riparian zone and clearcut logging likely created historic spikes in sediment supply and greater runoff. With more conservative timber harvest practices and associated protective buffer width requirements in effect since 2005, future sediment yield is expected to decline and return to a lower background level.

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Longitudinal profiles were developed from 2019 LiDAR data (Figure 14; USGS and Quantum Spatial 2019). 2020 survey data collected by WSDOT indicates that the channel elevations in the LiDAR data profile are higher than actual, but the bias appears to be consistent away from the road prism. The profiles were used to identify significant landmarks and breaks in the channel gradient along the tributary and West Fork Hoquiam River that would influence spatial variation in sediment transport and deposition patterns. The channel upstream of the culvert is generally steep (1.8%) and appears to be a transport reach. The gradient drops significantly at the culvert (0.3%), and then increases to 7.1% over the short distance between the culvert and the West Fork Hoquiam River. At the confluence, the West Fork Hoquiam River has a gradient of 0.9%, but the lack of deposits from the project stream suggests the sediment transport capacity of the West Fork Hoquiam is sufficient to carry away material delivered from the project stream. In general, the profile depicted in Figure 14 suggests that aggradation is less likely than degradation, where the constructed channel may regrade to be in line with the upstream grade. The maximum amount of degradation based on extending the upstream profile downstream is approximately 2 feet at the outlet, and less than -0.5 feet at the inlet (cf Figure 14).

The break in gradient at the crossing would be expected to be associated with aggradation of gravel material over the long term. Finer grained material is likely to be transported to the short reach between the culvert and the West Fork Hoquiam River, and washed downstream by high flows and overbank flows in both channels. The maximum amount of localized aggradation associated with gravel deposition would be expected to scale with the height of the tributary's streambanks or around 1-1.5 feet. Assuming the channel is filled completely with gravel, additional gravel would be expected to form a wide depositional fan. Given no such fan is seen presently, there is a defined channel morphology, and gravel transport from upstream is not extensive, it is inferred that future channel aggradation in the vicinity of the crossing can be expected to be less than 1.5 feet.

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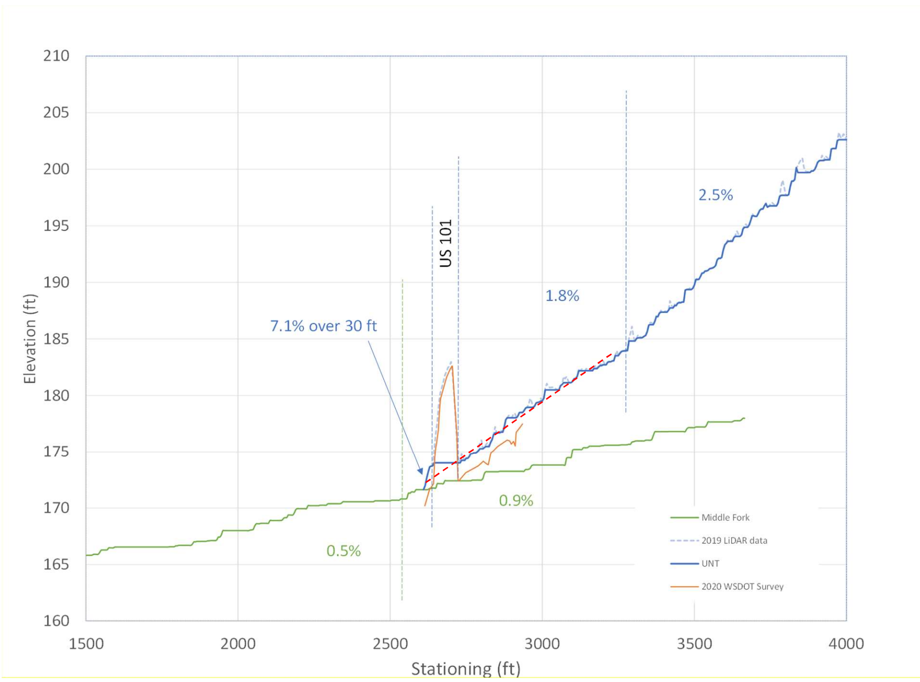

Figure 14: Watershed-scale longitudinal profile and gradients of the Middle Fork Hoquiam River and project stream; plot includes comparison of LiDAR with WSDOT survey data; dashed red line is upstream grade extended downstream

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While there is limited potential for localized channel aggradation upstream of US 101 currently under existing conditions, the possibility exists that potential future profile adjustments downstream in the West Fork Hoquiam River could lead to profile adjustments in the project stream in the vicinity of the crossing, where the adjustment could be associated with degradation or aggradation depending on circumstances as described below. The overall grade lower down in the project stream appears to be influenced by grade control processes in the West Fork. In particular, there are presently a series of 3 wood-forced steps in the West Fork, with the first step located 100 ft downstream of the culvert.

2.8.4.1 Channel Degradation Associated with Changes in the West Fork Hoquiam River

The West Fork Hoquiam River profile does not indicate any significant discontinuities, and the confluence is upstream of another reduction in grade (Figure 14). In section 2.8.5, no historical lateral migration was observed, and the potential for avulsion was deemed unlikely. However, the wood steps downstream of the confluence could deteriorate and possibly wash out, lowering the grade control up to 1.0 foot or a low of 170.6 feet. Because the West Fork Hoquiam River sets the fundamental base level grade control for the creek, lowering of the mainstem grade would propagate upstream, 100 feet on the mainstem and 30 feet up the tributary. The average gradient of the West Fork is 0.9%. The minimum slope observed upstream of the crossing (1.8%) provides a conservative estimate of the expected regrade slope and so this scenario sets the minimum plausible channel grade at the downstream side of the crossing by extending the profile as discussed above, down to approximately elevation 172.1 ft. Because this elevation is based on several conservative additive assumptions, it is relatively unlikely that the stream bed will lower to this elevation over the design life of the culvert. This amount of degradation is especially unlikely given hydraulic modeling of flood flow for both systems; this shows a significant backwater control from the West Fork (source), that may reduce the propensity for flows in the project stream to cause incision during coincident high flow events.

2.8.4.2 Channel Aggradation Associated with Changes in the West Fork Hoquiam River

The West Fork Hoquiam River watershed is approximately an order of magnitude larger than the project stream at the crossing, and the channel is accordingly wider and can transport LWM. There is a possibility, albeit what is judged to be a relatively low probability, that a channel spanning log jam on the West Fork Hoquiam River would cause aggradation at the crossing. Steps over spanning, buried wood in the project stream bottom indicate that at least 1 ft of aggradation has occurred over such features in the past. Typical guidance for profile variability in larger, gravel bed rivers in Western Washington (Rapp and Abbe 2003) indicates that at least 2m (7 ft) of aggradation should be considered possible, but this scales with the size of wood transported and the transport and deposition of significant quantities of large gravel. The West Fork does not appear to transport significant volumes of coarse gravel, or large diameter logs. Moreover, the most likely location for racking logs downstream is where the wood steps are located, where the West Fork Hoquiam River would have to aggrade more than 3 feet locally before impacting the project stream at the US 101 crossing. Given the evidence of some historic local incision of 1.5 feet in the river downstream, the presence of a defined channel cross-section downstream of the crossing that is not substantially shallower than upstream, and the generally consistent grade of the West Fork, the risk of significant aggradation is considered relatively low at this site.

2.8.5 ***Channel Migration***

Channel migration was assessed for both the project stream and the West Fork Hoquiam River based on topography and field observations. The project stream and West Fork are generally too small and canopy too thick for aerial photography to be of use for evaluating migration history.

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2.8.5.1 Project Stream

While the stream is markedly sinuous upstream of the culvert, it does not exhibit signs of significant channel meandering or avulsion, with the planform constrained by large wood, established trees growing in the banks, and the adjacent hillside. Hydraulic modeling indicates that the 2-year flood is generally confined in much of the reference reach upstream of the crossing, with no floodplain flow paths engaged (Appendix C). Downstream of the culvert, velocities in the project stream are low during floods because of backwater from the West Fork Hoquiam River. Consequently, the project stream is not expected to exhibit significant channel migration sufficient to influence the design.

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2.8.5.2 West Fork Hoquiam River

While there were no signs of significant channel migration by the West Fork Hoquiam River, the dominant shrub cover along the streambank and floodplain between the river and the culvert would not be expected to prevent bank erosion along the river left bank in the vicinity of the confluence. Hydraulic sheltering is provided by mature trees growing on the left bank and floodplain upstream, but additional protection against erosion at the confluence could be provided through strategic large wood placement along the right bank of the tributary channel.

2.8.6 ***Riparian Conditions, Large Wood, and Other Habitat Features***

The banks in the upstream reach proximal to the culvert inlet are vegetated with a dense shrub layer. The understory becomes more open moving upstream, where the forest canopy is denser. The riparian corridor consists of a mixed mature forest composed primarily of alder, western hemlock, and Douglas fir. There is a dense shrub understory with native species including salmonberry (*Rubus spectabilis*), vine maple (*Acer circinatum*), salal (*Gaultheria shallon*), and sword fern (*Polystichum munitum*). The mature forest and shrub cover provides good shading, nutrient inputs, and some potential for LWM recruitment. Measurements of mobile pieces upstream of the culvert indicates that pieces longer than about 7 feet and thicker than about 5 inches in diameter are not transported far and become racked up on larger pieces of wood and brush. Trees that fall into or across the channel remain generally in place.

There were five places where logs and woody material were noted in the stream channel and banks, and a total of 14 key pieces of LWM. These logs ranged from 6 to 48 inches in diameter. A small cascade is formed by several pieces of LWM in the streambed near the midpoint of the surveyed reach. Downstream of the crossing, a short reach joins the West Fork Hoquiam River within approximately 30 feet of the culvert outlet. The riparian corridor is predominantly roadside shrub and forb vegetation because of its proximity to the U.S. 101 road prism. The riparian corridor is constrained on the left bank of the stream because of its proximity to the highway. There is a dense shrub understory with native species including salmonberry (*Rubus spectabilis*), willows (*Salix spp.*), Devils club (*Oplopanax horridus*), sedges, and non-native species including Himalayan blackberry (*Rubus armeniacus*). At the West Fork

Hoquiam River, there are some alders and a few fir trees along the left bank where the unnamed tributary confluence is located, and large cedars (*Thuja plicata*) on the opposite bank.

An embedded rootwad located on the left bank at the confluence is undercut by flows from the unnamed tributary that pass through a small opening underneath. A natural log weir spans the channel of the West Fork Hoquiam River just downstream of the confluence with the unnamed tributary, and forms a large pool. This pool is located at the confluence, and a large fallen tree is lying across the banks above the wetted channel.

WDFW completed a physical survey in 2005 at the site (WDFW 2005). No beaver dams or beaver sign was observed upstream and downstream of the crossing during the WDFW survey and in any of the site field visits.

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3 Hydrology and Peak Flow Estimates

The project stream drains an ungaged basin, with no long-term historical flow data available. No hydrologic studies, models, or reports were found that summarized peak flows in the basin. Consequently, USGS regression equations (Mastin et al. 2016; Region 4) were used to estimate peak flows at the U.S. 101 crossing. Inputs to the regression equation included basin size and mean annual precipitation. The unnamed tributary has a basin area of 0.22 square mile above the culvert and a mean annual precipitation within the basin of 102.8 inches (PRISM Climate Group 2019). LiDAR data acquired along with the survey data directly from WSDOT. The catchment was delineated using Arc Hydro to determine drainage areas and precipitation values as inputs for the regression equations.

The hydraulic model extents also includes the confluence with the West Fork Hoquiam River and as a result it was necessary to estimate peak flows for the West Fork River. Similar to the project stream, peak flows were estimated for the West Fork Hoquiam River using the USGS regression equations. Just upstream of confluence, the West Fork Hoquiam River has a delineated watershed area of 1.87 square miles and a mean annual precipitation of 105.1 inches (PRISM Climate Group 2019).

The resulting regression estimates (Table 5) were evaluated for potential sub-regional bias by comparing regression predictions against estimates derived at selected stream gages in the area using available flow records. A Washington Department of Ecology gage was identified from the Wishkah River, but only USGS gages were found with a sufficiently long period of record (>20 years) in the area to permit evaluating the larger predicted flood peaks (Table 6).

Peak flow data were analyzed for each gage following the Bulletin 17B methodology for peak flow frequency analysis, using the Hydraulic Engineering Center's Statistical Software Package (HEC-SSP) version 2.2. HEC-SSP uses the Log Pearson Type III distribution for annual peak flows on unregulated streams, fit by the Method of Moments. Distribution parameters were estimated for the 2-, 10-, 100-, and 500-year return intervals based on moments of the sample data (site-specific). Adjustments were made for non-standard data, low outliers, and historical events. The resulting peak flow estimates were compared against the regression estimates using the equations in Mastin et al. (2006), where drainage area and mean annual precipitation estimates were determined using USGS' StreamStats web application. The ratio of gage-based to regression-based estimates was then plotted against drainage area (Figure 15). The results indicate that the regression estimates for smaller basins may be generally comparable to or higher than would be derived using gage data. As corroboration, a modeling exercise performed for Culvert ID 993704 using the MGS Flood model indicated that the regression estimates for a similarly sized, nearby drainage area were higher than values estimated based on a more direct simulation of stormwater rainfall-runoff processes. The regression estimates accordingly appear to be more conservative.

Consequently, the regression estimates in Table 5 were used in design development, to provide a safety factor when designing for flood conveyance, freeboard, channel stability, and scour. The 2080 predicted 100-year flow determination provides context for addressing climate change, as described in Section 7.2.

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Summer low-flow conditions are unknown and high/low fish passage design flows are not included in this analysis. The stream was observed to still be flowing in mid-August 2021.

Table 5: USGS regression-based estimates of peak flow

Mean recurrence interval (MRI) (years)	Unnamed tributary USGS regression equation (Region 4) (cfs)	West Fork Hoquiam River USGS regression equation (Region 4) (cfs)	Regression standard error (percent)
2	21.7	159	52.5
10	37.8	276	50.5
25	45.6	333	51.7
50	51.6	378	52.9
100	58.4	428	54.2
500	72.2	533	58.0
2080 predicted 100	63.2	467	NA

Table 6: Local USGS gages used to evaluate bias in USGS regression predictions

Station #	Gage Name	Years of Record
12039005	Humptulips River Below Hwy 101	2002-2018
12036000	Wynoochee River Above Save Creek Near Aberdeen, WA	1952-2018
12035500	Wynoochee River at Oxbow Near Aberdeen, WA	1925-1952
12035450	Big Creek near Grisdale, WA	1972-1996
12035400	Wynoochee River near Grisdale, WA	1965-2018
12039050	Big Creek near Hoquiam, WA	1949-1970
12039100	Big Creek Tributary near Hoquiam, WA	1949-1968

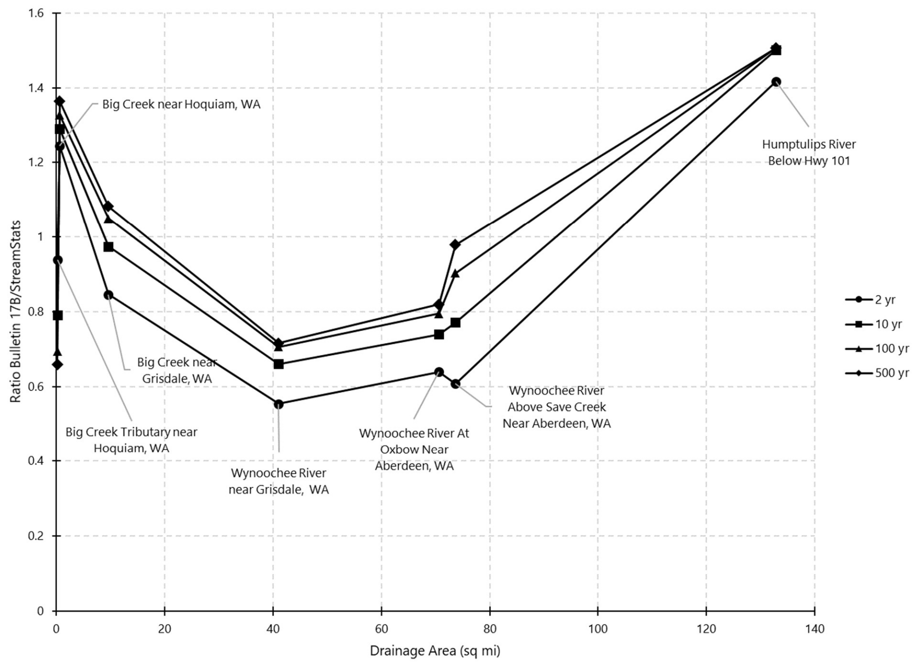

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Figure 15: Ratio of gage-based flood peak magnitudes vs. regression-based estimates, plotted against drainage area

4 Hydraulic Analysis and Design

The hydraulic analysis of the existing and proposed crossing was performed using the United States Bureau of Reclamation's (USBR's) SRH-2D Version 3.0 computer program, a two-dimensional (2D) hydraulic and sediment transport numerical model (USBR 2017). Pre- and post-processing for this model was completed using SMS Version 13.1.11 (Aquaveo 2021).

Three scenarios were analyzed for determining stream characteristics for the unnamed tributary with the SRH-2D models: (1) existing conditions with a 3-foot concrete culvert through the crossing, (2) estimated natural conditions with the roadway embankment and culvert removed, and (3) future conditions with the proposed 13-foot hydraulic opening.

Because of the proximity of the crossing to the confluence with the West Fork Hoquiam River, the crossing may be subject to backwater from the mainstem during flood events. Accordingly, two sets of alternate scenarios were run for each existing-, proposed-, and natural-conditions model. The first set of simulations, herein described as the *tributary scenario,* includes one flow time series upstream boundary condition on the unnamed tributary with no flow present on the West Fork. The second set of simulations, herein described as the *coincident peaks scenario,* describes a set of scenarios that includes flow time series upstream boundary conditions on the unnamed tributary and the West Fork Hoquiam River. The six simulations run for the existing-, proposed-, and natural-conditions models are described as *2-year tributary, 100-year tributary, 500-tributary, 2-year coincident, 100-year coincident, and 500-year coincident.* Model simulations were run for a sufficiently long duration until the results stabilized across the model domain.

4.1 Model Development

This section describes the development of the model used for the hydraulic analysis and design.

4.1.1 *Topographic and Bathymetric Data*

The channel geometry data in the model were obtained from the MicroStation and InRoads files supplied by the Project Engineer's Office (PEO), which were developed from topographic surveys performed by WSDOT prior to March 13, 2020. The survey data, representing channel features and sections of U.S. 101, were supplemented with LiDAR data by WSDOT. Detailed channel survey extended 70 feet downstream of the crossing and 200 feet upstream of the crossing. Proposed channel geometry was developed from a proposed grading surface created initially by HDR. All survey and LiDAR data are referenced to the North American Vertical Datum of 1988 (NAVD88) using U.S. Survey feet.

4.1.2 *Model Extent and Computational Mesh*

The hydraulic model upstream and downstream extents start and end with LiDAR beyond the detailed topographic survey data for the West Fork Hoquiam River and unnamed tributary. The detailed survey data were combined with the LiDAR by WSDOT, and started approximately 200 feet upstream of the existing culvert inlet measured along the channel centerline. The upstream domain limit was selected to be far enough upstream to include the reference reach and allow the model to simulate lateral velocity variation in the areas of concern. Two to three floodplain widths of additional LiDAR should be applied upstream of survey data if data were available. A similar approach would be ideally applied to the downstream boundary condition. However, the survey data only extend about 70 feet downstream of the confluence of the unnamed tributary with the West Fork Hoquiam River. LiDAR data in the channel were 2 to 3 feet higher than the surveyed channel bottom, indicating that the channel thalweg would not be estimated reasonably with LiDAR data downstream of the survey. For this reason, the downstream extent of the model is located roughly at the end of the survey extent, about 60 feet downstream of the crossing.

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The computational mesh elements are a combination of patched (quadrilateral) and paved (triangular) elements, with finer resolution in the channel and larger elements in the floodplain. The existing conditions model mesh covers a total area of 86,999 square feet (SF) with 7,020 quadrilateral and 56,067 triangular elements (Figure 16). The natural conditions model mesh covers a total area of 86,986 SF, with 6,284 quadrilateral, and 57,484 triangular elements (Figure 17). The proposed PHD mesh covers a total area of 81,016 SF, with 6,368 quadrilateral and 49,919 triangular elements (Figure 18).

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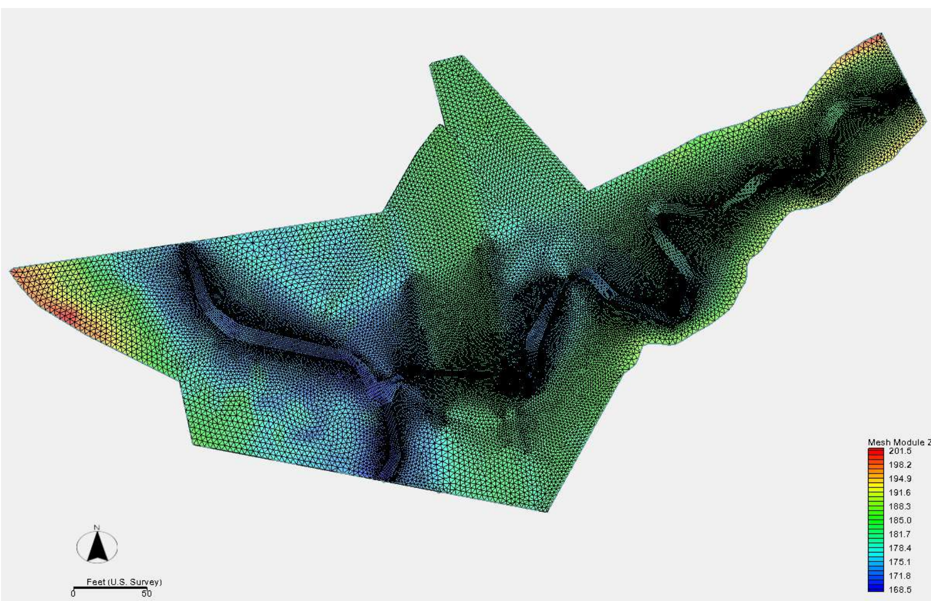

Figure 16: Existing-conditions computational mesh with underlying terrain

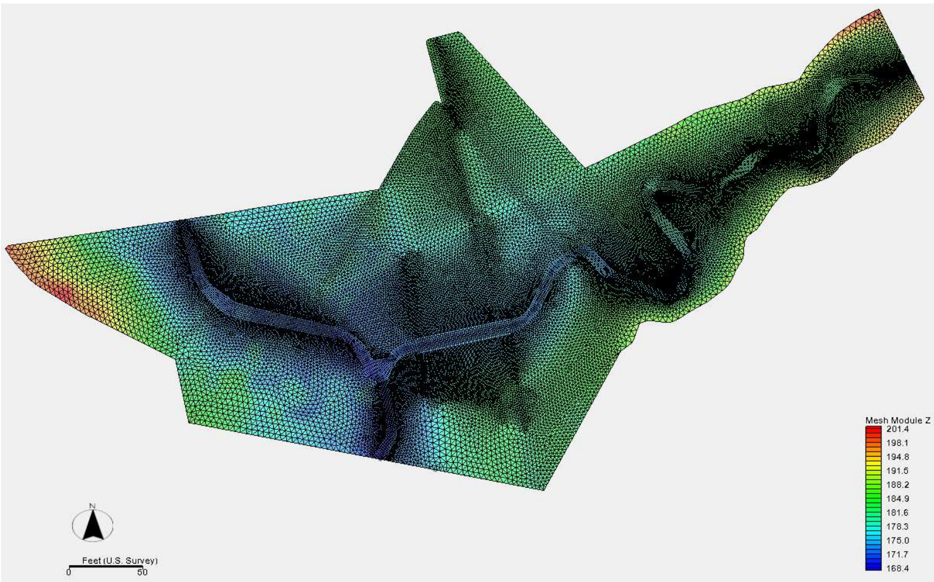

Figure 17: Natural-conditions computational mesh with underlying terrain

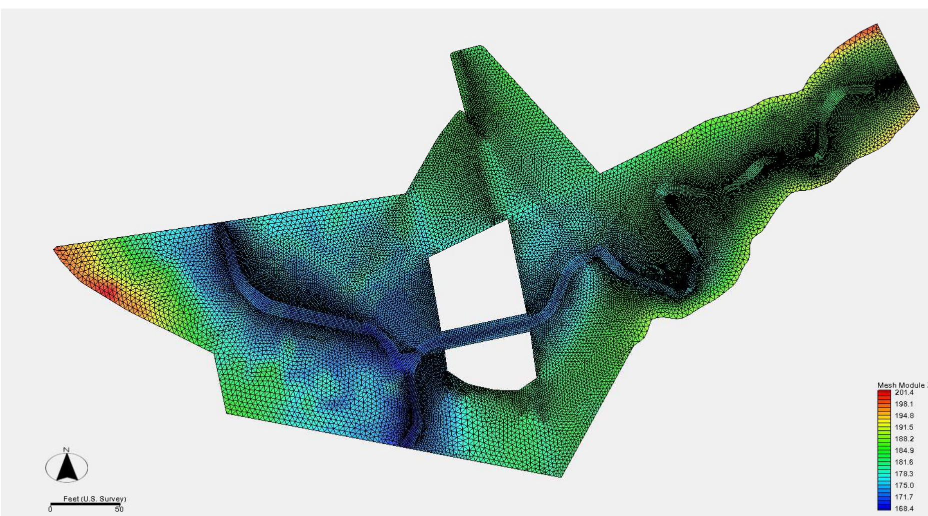

Figure 18: Proposed-conditions computational mesh with underlying terrain

4.1.3 ***Materials/Roughness***

Manning's n values were estimated for the natural channel and floodplain of the project stream using the Cowan method based on site observations (Arcement and Schneider 1989; see Appendix G). A channel value was also estimated for the West Fork Hoquiam River. The resulting values were consistent with standard engineering values for 1-D simulations (Barnes 1967). The value for the culvert was estimated using the same reference, with a base value of n=0.035 for a gravel-cobble mix, and with 0.01 added to account for low profile bedforms that will be part of the final design (see Section 4.4). The resulting 1-D values were then adjusted down by 10 percent to reflect generally expected reductions when moving to a 2-D model parameterization (Robinson et al. 2019; Table 7). Figures 19, 20, and 21 depict the spatial distribution of hydraulic roughness coefficient values for the existing, natural, and proposed condition scenarios, respectively.

Table 7: Manning's n hydraulic roughness coefficient values used in the SRH-2D model

Land cover type	Manning's n
Forest	0.095
Floodplain	0.095
Stream Channel	0.075
W. Fork Hoquiam River Channel	0.050
Paved roadway	0.020
Roadway Embankment/Irregular Fill	0.040
Within Proposed Crossing	0.041

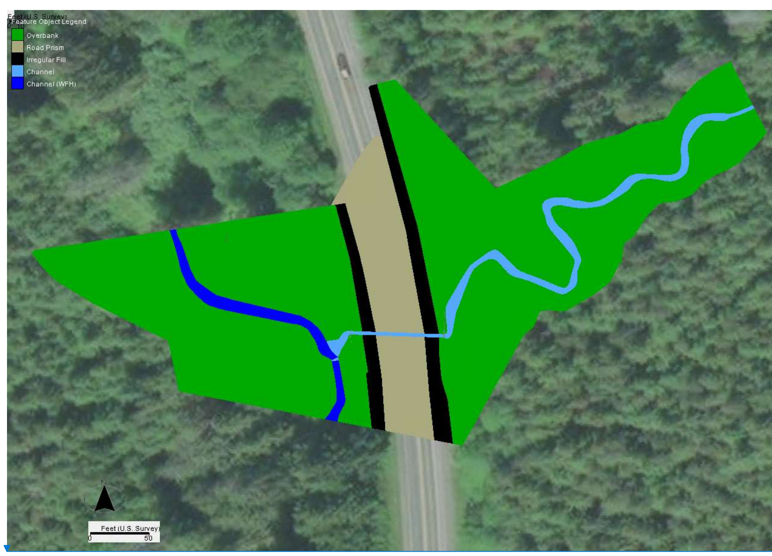

Figure 19: Spatial distribution of roughness values in SRH-2D existing-conditions model

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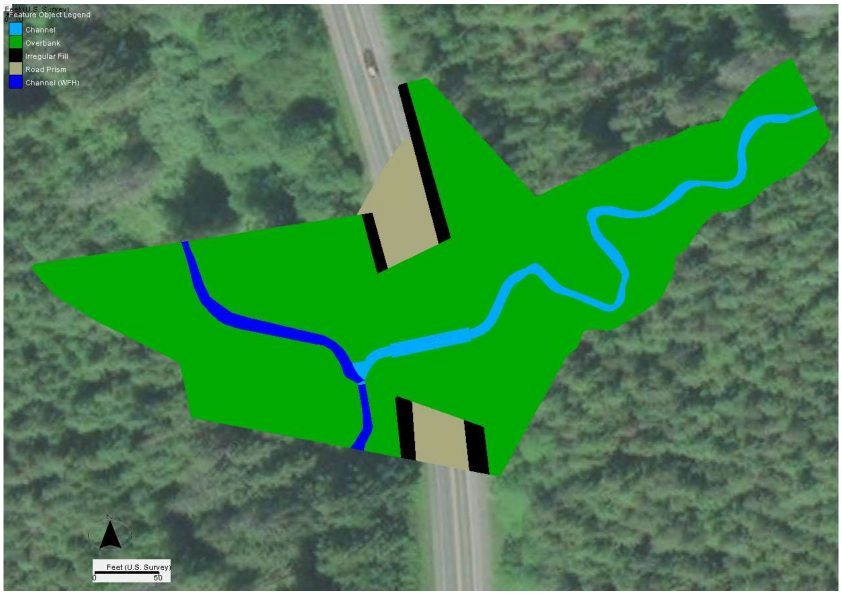

Figure 20: Spatial distribution of roughness values in SRH-2D natural-conditions model

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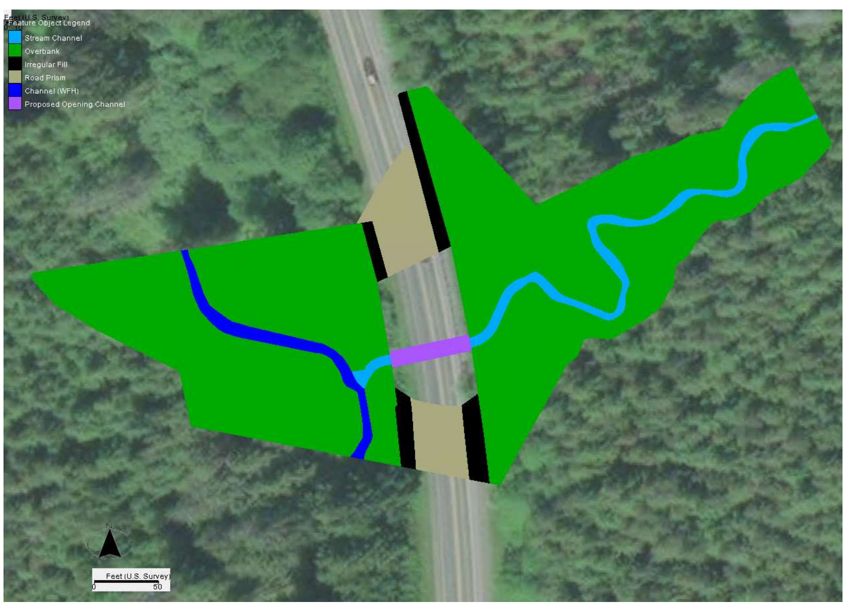

Figure 21: Spatial distribution of roughness values in SRH-2D proposed-conditions model

4.1.4 ***Boundary Conditions***

Model simulations were performed using time series discharges ranging from the 2-year to 500-year peak flow events summarized in Section 3. External boundary conditions were applied at the upstream and downstream extents of the model domain and remained the same between the existing-, natural-, and proposed-conditions runs. A time varied flow rate was specified at the upstream external boundary conditions for the project stream (Figure 22) and West Fork Hoquiam River (Figure 23). A normal depth rating curve was used to specify a flow dependent water surface elevation at the downstream boundary in the West Fork (Figure 24). A sensitivity analysis was performed during early model development of the effect of error in the downstream normal depth slope. This analysis determined that the water surface elevations and velocities at the downstream end of the crossing are not sensitive to the downstream boundary. The downstream boundary was accordingly placed such that the model results for the existing and proposed culvert conditions were influenced the least by the downstream boundary condition. The locations of each boundary condition for the existing and proposed conditions for each case are identified in Figures 25-28.

An HY-8 internal boundary condition was specified in the existing-conditions model to represent the existing circular concrete culvert crossing (Figure 29). The existing crossing was modeled as a 3-foot-diameter circular pipe within HY-8. A Manning's roughness of 0.012 was assigned to the culvert. The culvert was assumed to be unobstructed and free from any stream material within the barrel. The HY-8 internal boundary conditions were removed for the natural and proposed scenarios. To represent the edge of the proposed structure, a slip boundary was added outside of the proposed channel within the roadway. The addition of this boundary condition to all proposed conditions simulates a more realistic interaction between flow and the edge of proposed structure.

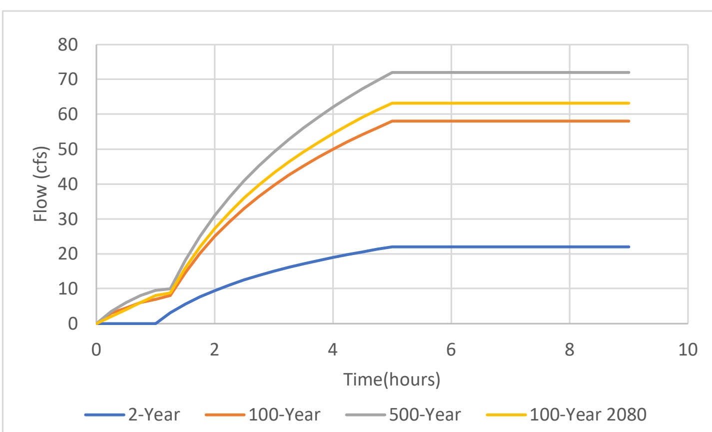

Figure 22: Time series of upstream flow boundary condition: unnamed tributary

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The models were run for two cases, where only the tributary had high flows, and where both streams had high flows ("coincident peaks" scenarios). ...

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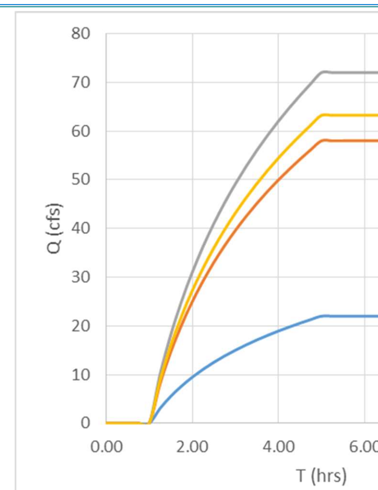

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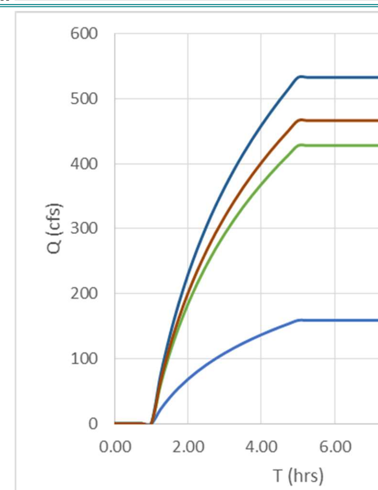

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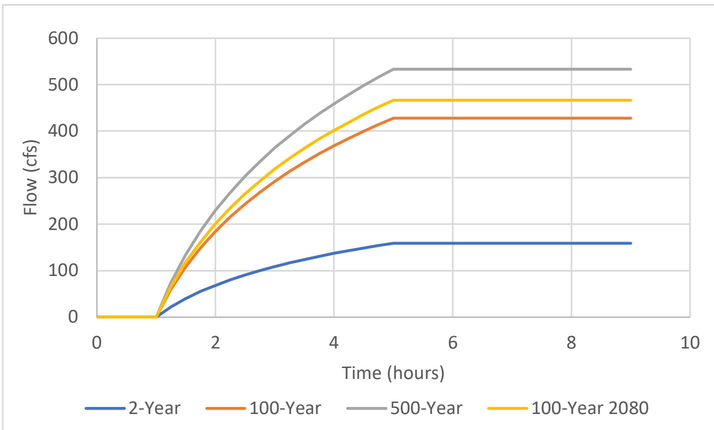

Figure 23: Time series of upstream flow boundary condition: West Fork Hoquiam River

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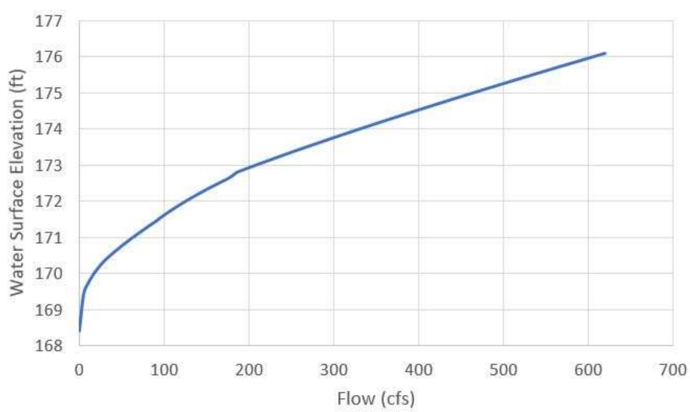

Figure 24: Downstream boundary condition normal depth rating curve on West Fork Hoquiam River (composite n=0.072 and slope=0.04)

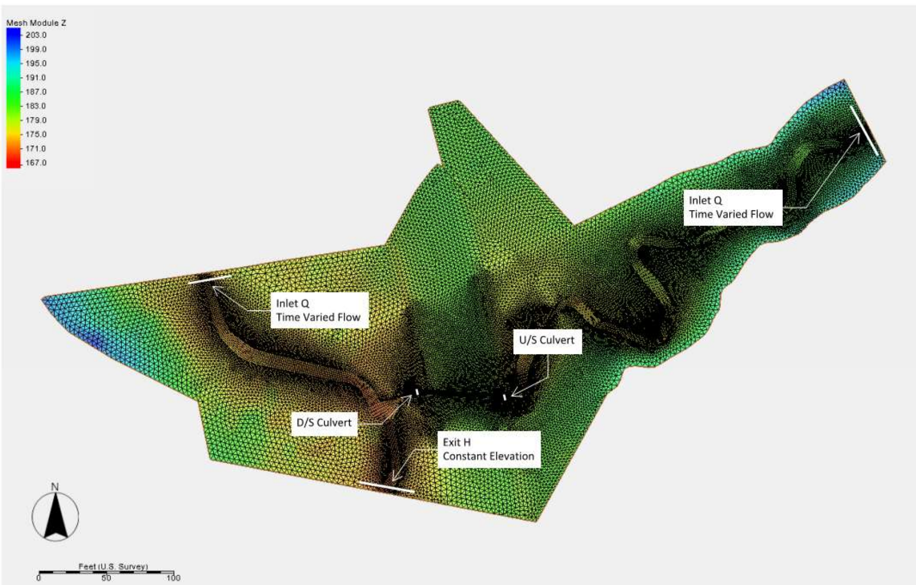

Figure 25: Location of boundary conditions for the coincident peaks existing-conditions model

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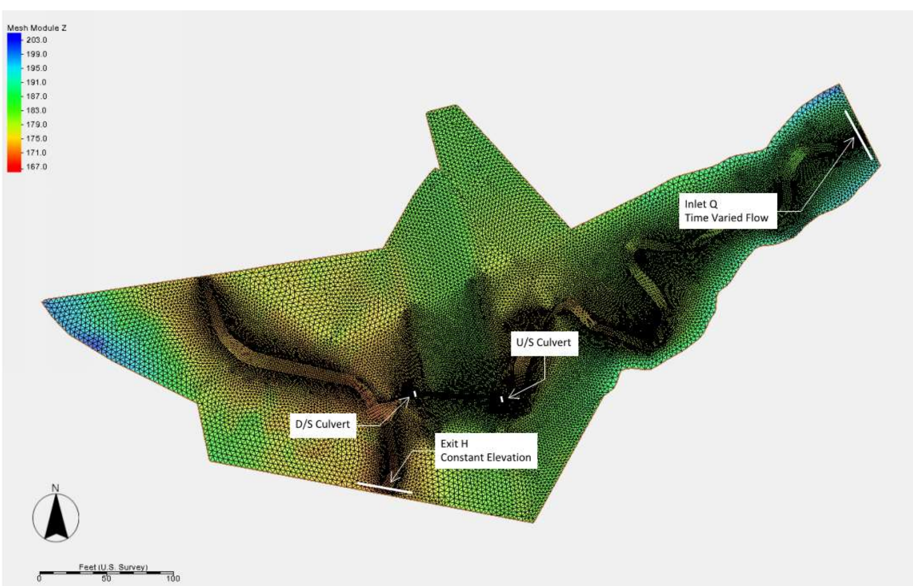

Figure 26: Location of boundary conditions for the tributary existing-conditions model

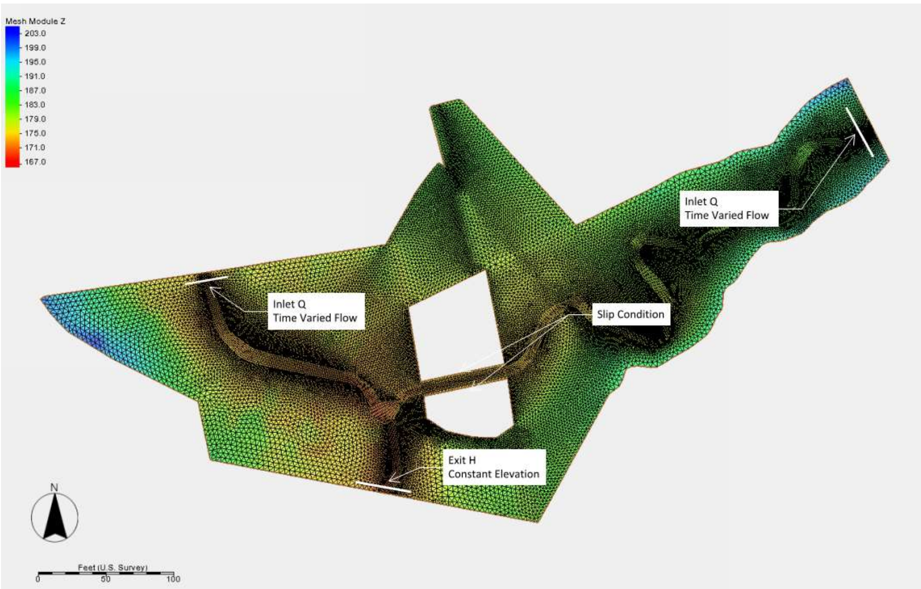

Figure 27: Location of boundary conditions for the coincident peaks proposed-conditions model

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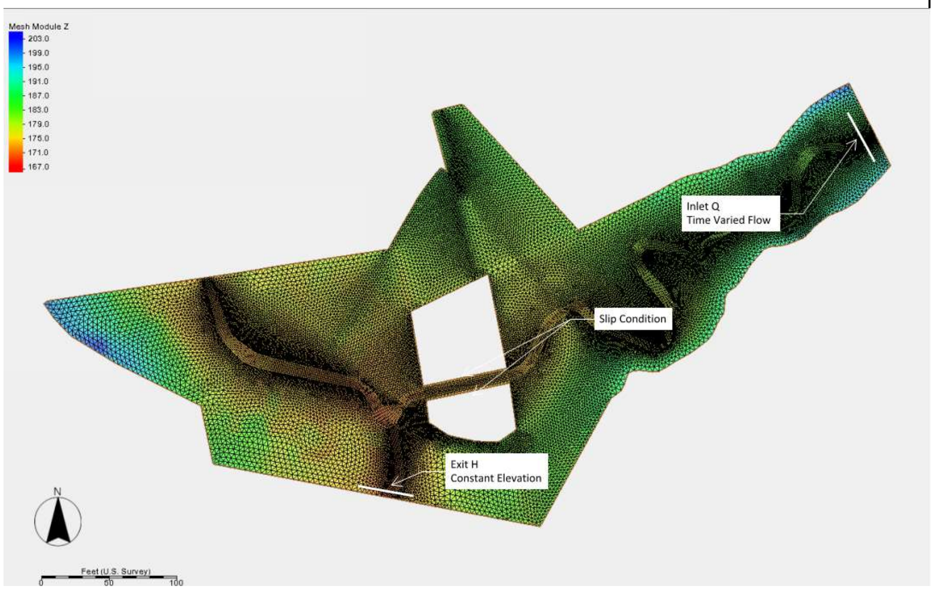

Figure 28: Location of boundary conditions for the tributary proposed-conditions model

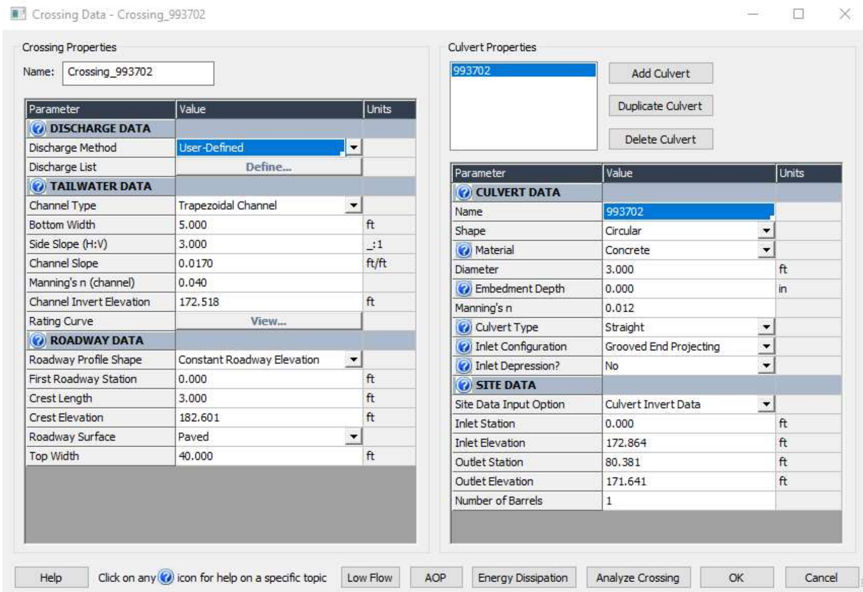

Figure 29: HY-8 culvert parameters, existing conditions model

4.1.5 *Model Run Controls*

All simulations were run using similar model controls. Model control variables were adjusted for model stability and adequate runtime to reach steady state. Most simulations were stable with a 1 second timestep, however some required a 0.1 second timestep to reduce instabilities. The following controls were set:

- Start Time: 0 hours
- Time Step; 0.1, 0.5 or 1 second
- End Time: 9 hours
- Initial Condition: Dry

The end time was adjusted during model development so that the duration was long enough to achieve steady-state conditions. The model was started at approximately 0 hour, with an appropriate time step, and was truncated after 9 hours for each existing-, natural-, and proposed-conditions simulation. Simulations for all 100-year and 500-year events were run with either a 0.5 or 0.1-second time step to achieve better stability in the model results. All scenarios were run with an initial dry condition.

4.1.6 *Model Assumptions and Limitations*

The SRH-2D hydraulic model was developed to determine the minimum hydraulic structure opening, establish the proposed structure low chord elevation (and associated freeboard), and characterize hydraulic parameters used to design the crossing structure, streambed, and LWM. There are several

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attributes of the data relied upon to develop the model that affect the resolution to which model output should be relied on. In particular, the survey data collected for developing the model terrain geometry were sufficient to capture macroscale variation in channel form and floodplain topography on the order of average channel width/depth/location and floodplain gradients. The spatial scatter of the survey point data was too coarse, however, to develop a model terrain capable of discerning an accurate and precise resolution of velocity distributions at smaller microtopographic scales, precluding predicting rapid spatial variation in hydraulic properties in association with bedform and instream roughness and flow obstruction variation. Accordingly, the designs are based on general, spatially averaged model predictions of velocity and shear stress, with an appropriate safety factor. Small scale variations in hydraulic properties should not be interpreted as signifying a meaningful feature of the design, Highly detailed design modeling of large wood structures is therefore not warranted, where structure stability and scour can be designed sufficiently using simply water depth and average channel values of velocity predicted by the model and increasing roughness locally.

In addition, the topographic extent of the area surveyed in some cases did not extend beyond the model predictions of inundation extent for the most extreme flood events, where the flooding extended onto the adjoining surface generated from the LiDAR data. As seen in Figure 14, the LiDAR data appear to be biased high along the stream channel. This results in artificially concentrating flood flows onto the area within the bounds of the survey, and thus potentially over-predicting water surface elevations

The use of a steady peak inflow rate is an appropriate assumption to meet design objectives at this site. Using a steady peak inflow rate provides a conservative estimate of inundation extents and water surface elevation (WSEL) associated with a given peak flow, which is used to determine the structure size and low chord, and loose LWM stability. Similarly, the model predictions of peak velocity are used to design general channel morphology, streambed composition, and both loose and fixed LWM stability. Each scenario is run for a sufficient time to fill storage areas and for WSELs to stabilize until flow upstream equals flow downstream. This modeling method does not account for the attenuation of peak flows between the actual upstream and downstream hydrographs, in particular with a large amount of storage upstream of the existing undersized culvert. During an actual runoff event, it is unlikely that the area upstream of the culvert would fill up entirely. An unsteady simulation could be used to route a hydrograph through the model to estimate peak flow attenuation for existing and proposed conditions. During an unsteady simulation, the areas upstream of the existing culvert would act as storage and, as a result, the flow downstream of the crossing would likely be less than the current design peak flow event. This is expected to be less of an issue for the natural conditions and proposed PHD scenarios at this site, however, where the channel size is small relative to the hydraulic opening, and the channel slope too steep, for flow attenuation effects to be significant.

The SRH-2D model outputs an estimate of shear stress that is calculated using a 2-D vector adaptation of the 1-D uniform flow approximation based on depth and energy slope. The program substitutes Manning's equation to calculate the slope, which results in shear stress estimate being proportional to the square of the Manning's n coefficient. Because Manning's n is used in the modeling as a surrogate for various energy losses in addition to grain friction, the resulting estimates of shear stress cannot be used to size streambed substrates or evaluate local scour depth. Values are presented in this report for

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general reference, but should be treated generally as substantial over-estimates of the actual boundary shear stress (e.g., Pasternack et al. 2006). This is addressed directly in Section 5.1.

The model results and recommendations in this report are based on the conditions of the project site and the associated watershed at the time of this design. Any modifications to the site, man-made or natural, could alter the analysis, findings, and recommendations contained herein and could invalidate the analysis, findings, and recommendations. Site conditions, completion of upstream or downstream projects, upstream or downstream land use changes, climate changes, vegetation changes, maintenance practice changes, or other factors may change over time. Additional analysis or updates may be required in the future as a result of these changes.

4.2 Existing-Conditions Model Results

Locations of the cross sections used to report results for the existing-conditions hydraulic model are shown in Figure 30. The stationing for each cross section is assigned using the existing alignment as shown in Figure 31. Throughout this report the cross sections are designated using the letters to allow for direct comparison between existing, natural, and proposed conditions at specific locations as the existing and proposed alignments vary.

The hydraulic model results presented at each cross section include WSEL, depth, velocity, and shear stress as shown in Tables 8 and 9. Most variables are average values for the main channel except depth as it is reported as the maximum. More detailed hydraulic model results are included in Appendix C. Results of the hydraulic model are also presented along the longitudinal profile for the existing conditions as shown in Figures 32 and 33. Representative cross-section profiles are shown in Figures 34 and 35. Figures 36 and 37 depict the spatial distribution of predicted velocities at the 100-year flood under both downstream boundary control scenarios.

Results from the coincident 2-year, 100-year, and 500-year simulations indicate that the West Fork Hoquiam River has considerable effect on the tailwater condition of the crossing due to the proximity of the outfall with the confluence of the West Fork Hoquiam River. The effect of the West Fork Hoquiam can be seen by the flat water surface profiles in Figure 32. For the tributary simulations, higher channel velocities are observed at the outfall, as would be expected without tailwater influence. Overtopping of the road is not predicted to occur in each simulation. However, the culvert is undersized. As a result, events above the 2-year event submerge the culvert inlet, resulting in backwater upstream of the culvert, characterized by a flat water surface profile and velocities between 1.0 and 1.4 ft/s immediately upstream of the existing culvert.

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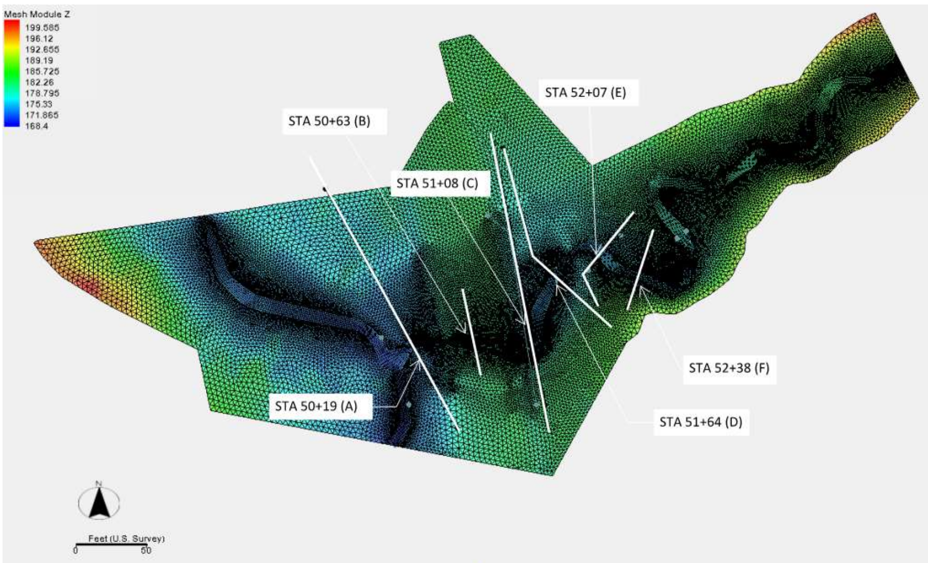

Figure 30: Locations of cross sections used for reporting results of existing conditions simulations

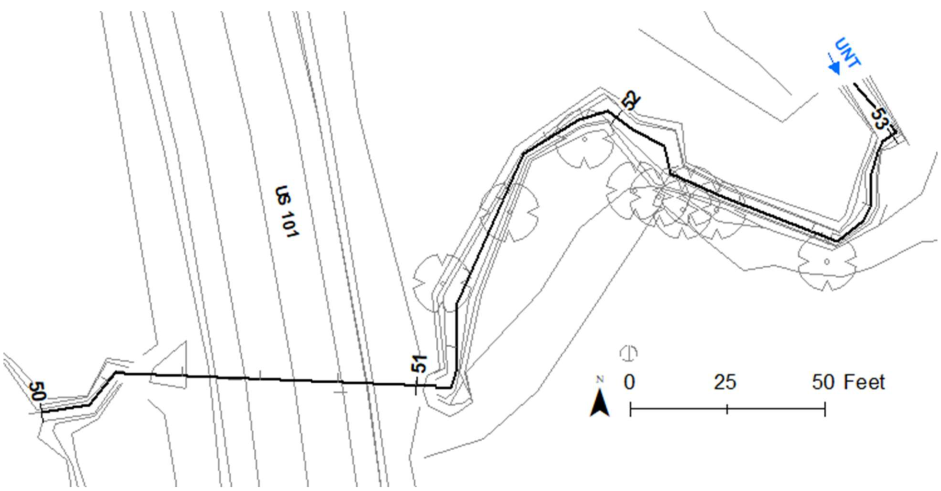

Figure 31: Longitudinal profile stationing for existing conditions

Table 8: Hydraulic results for existing conditions within main channel

Hydraulic parameter	Cross section (STA, name)	2-year coincident peaks	100-year coincident peaks	500-year coincident peaks	2-year tributary	100-year tributary	500-year tributary
Average WSEL (ft)	STA 50+19 (A)	174.9	176.4	176.8	173.3	173.7	173.9
	STA 50+63 (B)	NA	NA	NA	NA	NA	NA
	STA 51+08 (C)	175.4	178.7	180.2	175.1	177.2	178.4
	STA 51+64 (D)	175.5	178.7	180.2	175.3	177.3	178.4
	STA 52+07 (E)	176.4	178.8	180.2	176.4	177.7	178.5
	STA 52+38 (F)	177.0	178.8	180.2	177.0	177.9	178.6
Maximum water depth (ft)	STA 50+19 (A)	3.2	4.7	5.1	1.5	2.0	2.2
	STA 50+63 (B)	NA	NA	NA	NA	NA	NA
	STA 51+08 (C)	2.9	6.2	7.7	2.6	4.8	5.9
	STA 51+64 (D)	1.8	5.1	6.6	1.7	3.7	4.8
	STA 52+07 (E)	2.3	4.7	6.2	2.3	3.6	4.5
	STA 52+38 (F)	1.5	3.3	4.7	1.5	2.4	3.1
Average velocity magnitude (ft/s)	STA 50+19 (A)	1.4	2.6	2.9	3.0	3.6	3.9
	STA 50+63 (B)	NA	NA	NA	NA	NA	NA
	STA 51+08 (C)	1.0	1.1	1.1	1.1	1.4	1.4
	STA 51+64 (D)	2.8	0.8	0.4	3.5	1.8	1.1
	STA 52+07 (E)	1.1	0.9	0.6	1.2	1.6	1.3
	STA 52+38 (F)	3.5	2.0	1.2	3.5	4.0	2.8
Average shear stress (lb/SF)	STA 50+19 (A)	0.3	0.7	0.9	1.8	2.6	2.9
	STA 50+63 (B)	NA	NA	NA	NA	NA	NA
	STA 51+08 (C)	0.2	0.2	0.2	0.3	0.3	0.3
	STA 51+64 (D)	1.4	0.1	0.0	2.1	0.4	0.2
	STA 52+07 (E)	0.2	0.1	0.0	0.2	0.3	0.2
	STA 52+38 (F)	2.1	0.5	0.1	2.1	2.1	1.0

ft/s = feet per second.
lb/SF = pounds per square foot.

Table 9: Existing-conditions velocities at select cross sections for 100-year tributary simulation

Location	100-year tributary average velocities (ft/s)		
	LOB [a]	Main ch.	ROB [a]
STA 50+19 (A)	0.02	3.56	1.06
STA 50+63 (B)	NA	NA	NA
STA 51+08 (C)	0.92	1.37	0.33
STA 51+64 (D)	0.37	1.83	0.32
STA 52+07 (E)	1.38	1.56	0.17
STA 52+38 (F)	1.98	3.96	1.1

a. Right overbank (ROB)/left overbank (LOB) locations determined from the top of bank.
ft/s = feet per second.

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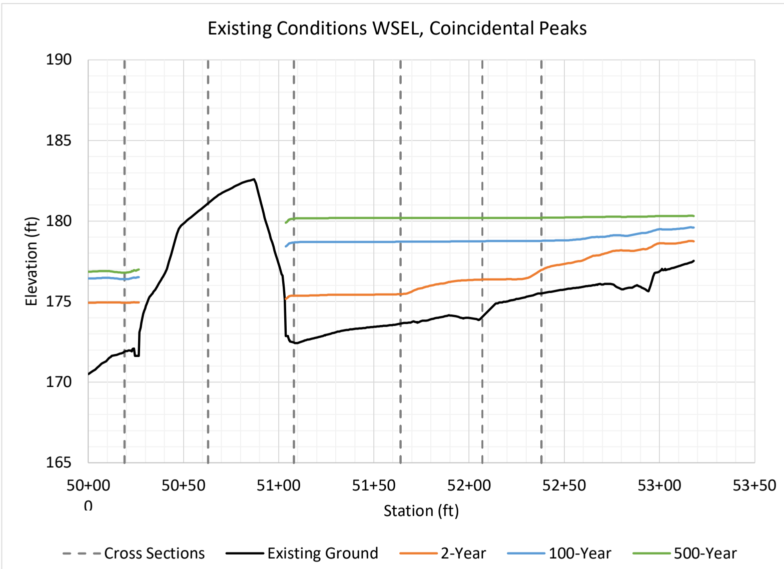

Figure 32: Existing-conditions water surface profiles, coincident peaks

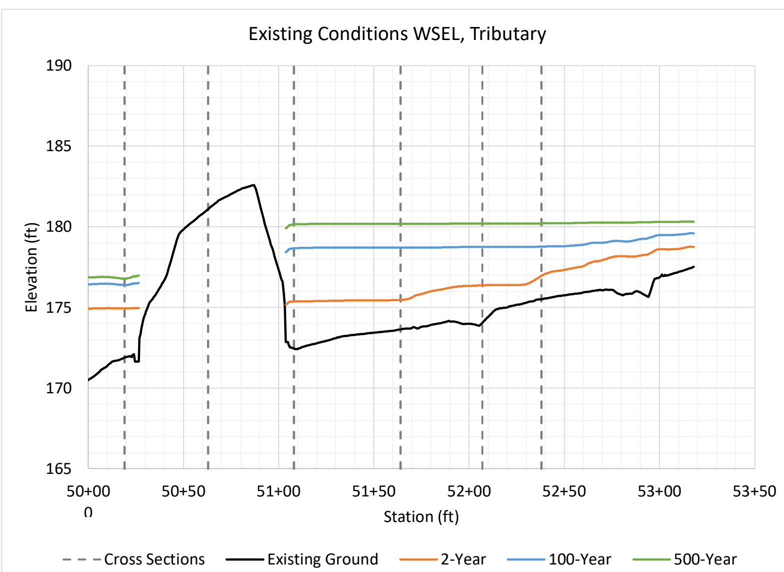

Figure 33: Existing-conditions water surface profiles, tributary only

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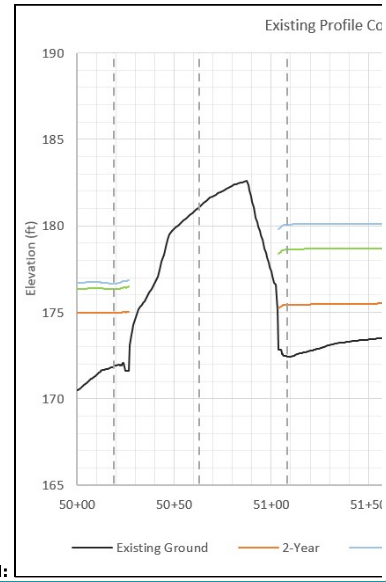

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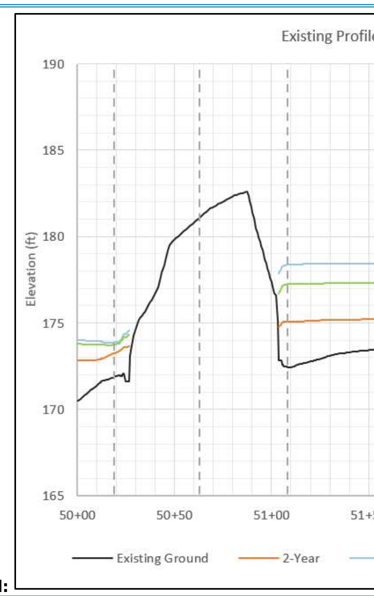

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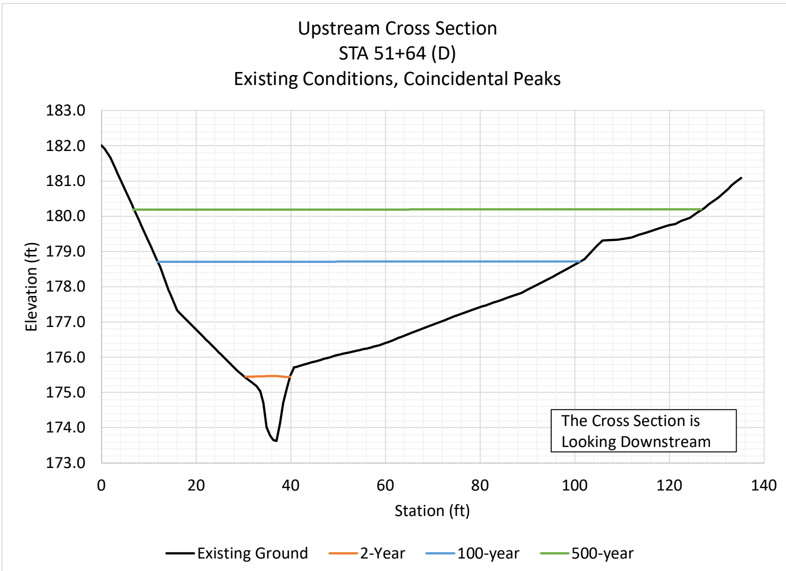

Figure 34: Typical upstream existing channel cross section (facing downstream), coincident peaks

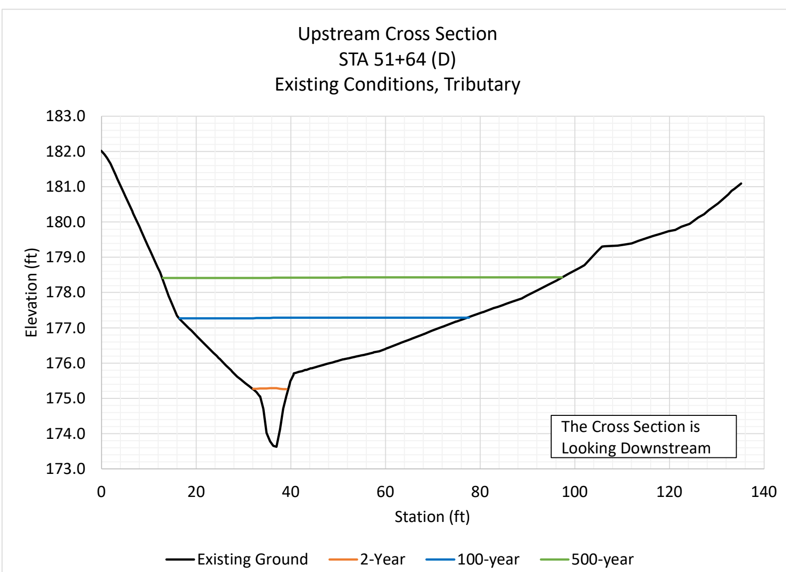

Figure 35: Typical upstream existing channel cross section (facing downstream), tributary only

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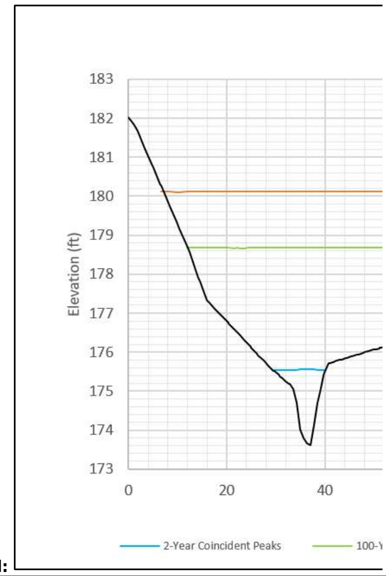

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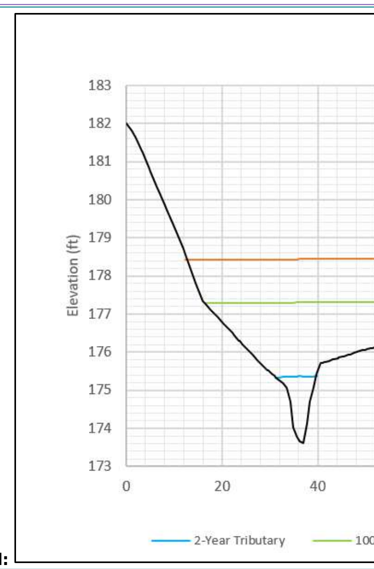

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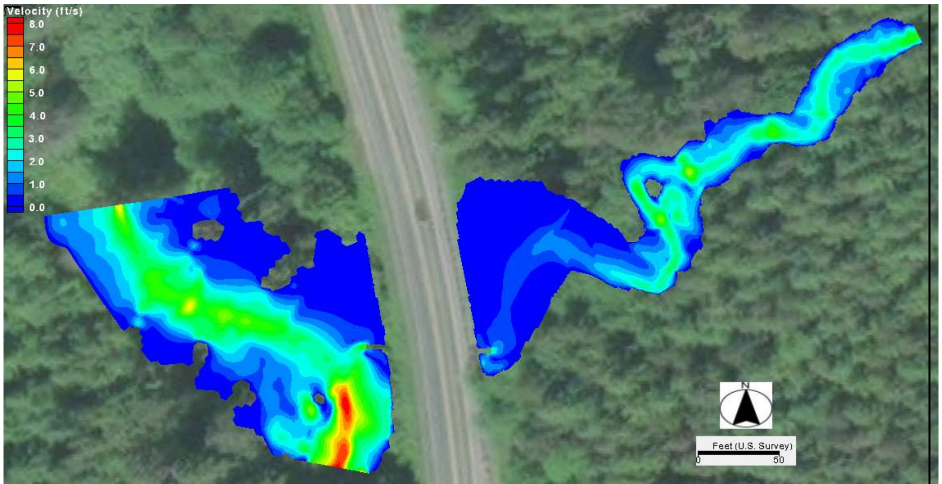

Figure 36: Existing-conditions present day 100-year velocity map (coincident peaks scenario)

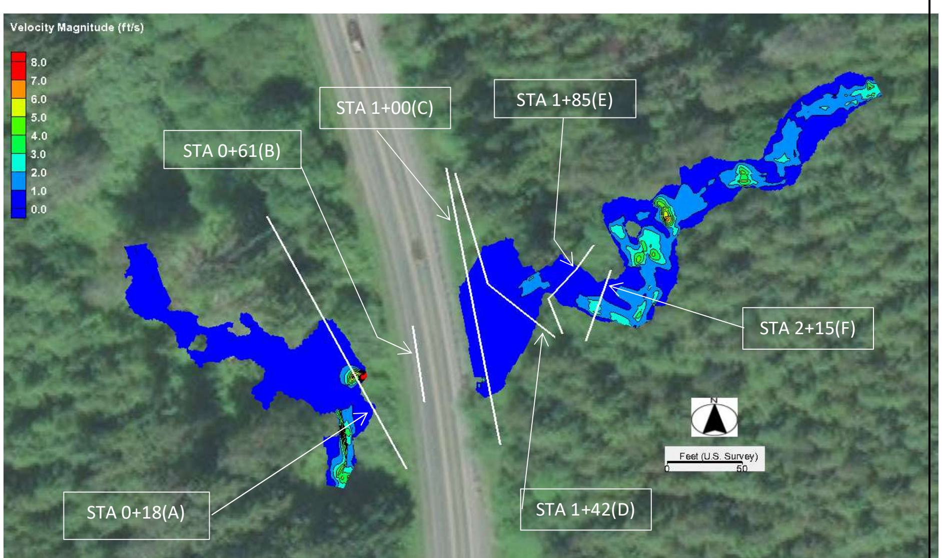

Figure 37: Existing-conditions present day 100-year velocity map (tributary only scenario)

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4.3 Natural-Conditions Model Results

Locations of the cross sections used to report results for the existing-conditions hydraulic model are shown in Figure 38. The existing culvert and alignment contain sharp bends in the stream and high gradients, creating high-velocity profiles. The natural conditions simulations use a modified alignment that reduces sharp channel bends at the structure and better matches the direction of overbank contours. This alignment is intended to match the tributary's natural condition prior to development. For the natural-conditions model, the roadway embankment and culvert were removed to approximate a floodplain at the location of the existing crossing.

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The hydraulic model results presented at each cross section include WSEL, depth, velocity, and shear stress as summarized in Tables 10 and 11. Most variables are average values along the channel except the depth as it is reported as the maximum. More detailed hydraulic model results are included in Appendix C. Predicted WSELs are presented along the longitudinal profile for the proposed conditions as shown in Figures 39 and 40. Representative cross-section profiles are shown in Figures 41-44 for peak flows. Figures 45 and 46 depict the spatial distribution of predicted velocities at the 100-year flood under both downstream boundary control scenarios.

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The natural coincident scenarios also indicate the crossing is heavily influenced by flows on the West Fork Hoquiam River. The tributary simulations demonstrate that a without tailwater influence, the channel is somewhat confined. Channel velocities in range from 2 to 5 ft/s. The velocity and shear distribution within the crossing is fairly even, lacking regions of high shear stress or velocity.

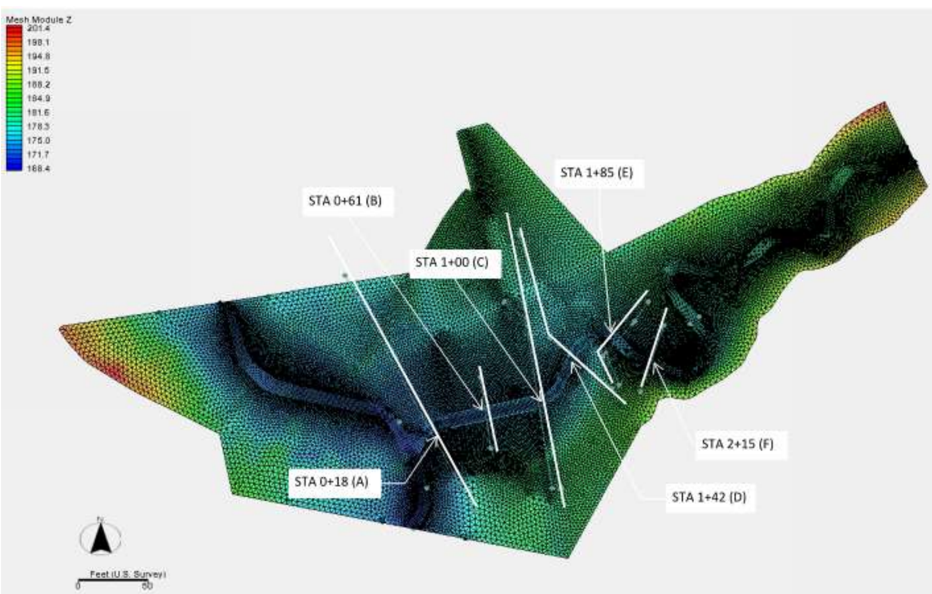

Figure 38: Locations of cross sections used for reporting results of natural conditions simulations

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Table 10: Hydraulic results for natural conditions within main channel

Hydraulic parameter	Cross section (STA, name)	2-year coincident peaks	100-year coincident peaks	500-year coincident peaks	2-year tributary	100-year tributary	500-year tributary
Average WSEL (ft)	STA 0+18 (A)	175.0	176.5	176.9	173.3	173.9	174.1
	STA 0+61 (B)	175.0	176.5	176.9	174.2	174.9	175.0
	STA 1+00 (C)	175.1	176.5	177.0	174.8	175.5	175.6
	STA 1+42 (D)	175.5	176.6	177.0	175.4	176.1	176.3
	STA 1+85 (E)	176.2	177.3	177.7	176.2	177.2	177.5
	STA 2+15 (F)	177.0	177.8	178.1	177.0	177.8	178.0
Maximum water depth (ft)	STA 0+18 (A)	3.2	4.7	5.1	1.5	2.1	2.3
	STA 0+61 (B)	2.6	4.0	4.4	1.7	2.4	2.6
	STA 1+00 (C)	2.1	3.5	3.9	1.7	2.4	2.6
	STA 1+42 (D)	1.8	2.9	3.3	1.7	2.4	2.6
	STA 1+85 (E)	2.1	3.3	3.6	2.1	3.2	3.5
	STA 2+15 (F)	1.5	2.3	2.5	1.5	2.3	2.5
Average velocity magnitude (ft/s)	STA 0+18 (A)	0.8	1.2	1.2	2.6	3.6	3.7
	STA 0+61 (B)	1.0	0.9	0.9	2.1	3.0	3.1
	STA 1+00 (C)	1.5	1.1	1.0	2.2	2.8	2.9
	STA 1+42 (D)	2.1	2.0	2.0	2.2	3.0	3.2
	STA 1+85 (E)	1.5	2.2	2.3	1.5	2.3	2.4
	STA 2+15 (F)	3.4	4.1	4.1	3.4	4.1	4.3
Average shear stress (lb/SF)	STA 0+18 (A)	0.1	0.2	0.2	1.5	2.3	2.4
	STA 0+61 (B)	0.2	0.1	0.1	0.9	1.5	1.6
	STA 1+00 (C)	0.4	0.2	0.2	1.0	1.3	1.4
	STA 1+42 (D)	0.9	0.7	0.6	1.0	1.5	1.7
	STA 1+85 (E)	0.4	0.7	0.7	0.4	0.8	0.9
	STA 2+15 (F)	2.3	2.8	2.8	2.3	2.9	2.9

ft/s = feet per second.
lb/SF = pounds per square foot.

Table 11: Natural-conditions average velocities predicted for 100-year flood over floodplains and in main channel at select cross sections

Location	Coincident Peaks 100-year Average Velocities (ft/s)			Tributary Only 100-year Average Velocities (ft/s)		
	LOB [a]	Main ch.	ROB [a]	LOB [a]	Main ch.	ROB [a]
STA 0+18 (A)	2.5	1.2	0.5	0.5	3.6	0.6
STA 0+61 (B)	0.5	0.9	0.5	1.2	3.0	1.1
STA 1+00 (C)	0.6	1.1	0.5	1.3	2.8	1.1
STA 1+42 (D)	0.5	2.0	0.7	0.9	3.0	1.1
STA 1+85 (E)	1.4	2.2	0.5	1.3	2.3	0.6
STA 2+15 (F)	1.9	4.1	1.1	1.9	4.1	1.1

a. Right overbank (ROB)/left overbank (LOB) locations determined from top of bank.

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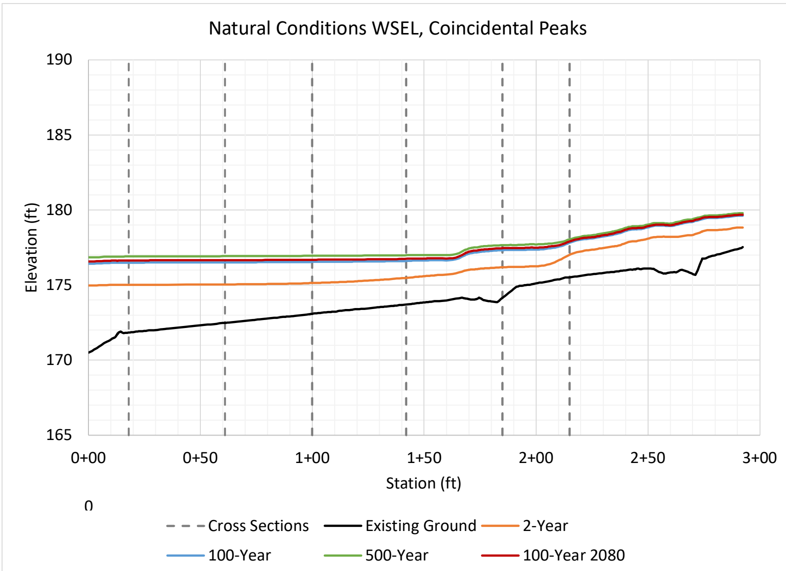

Figure 39: Natural-conditions water surface profiles, coincident peaks

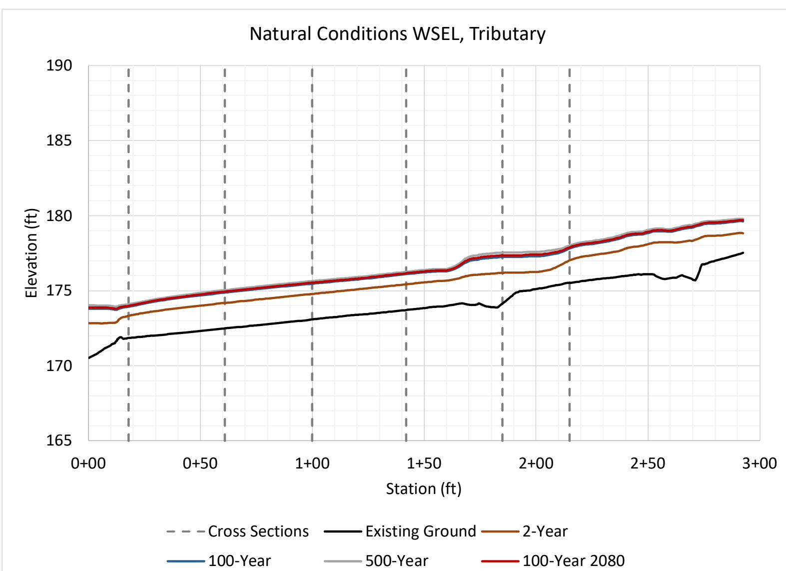

Figure 40: Natural-conditions water surface profiles, tributary only

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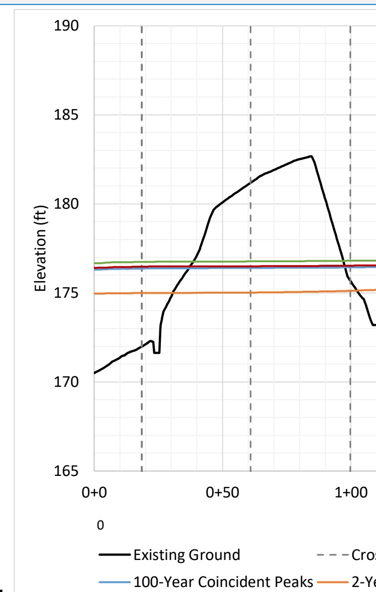

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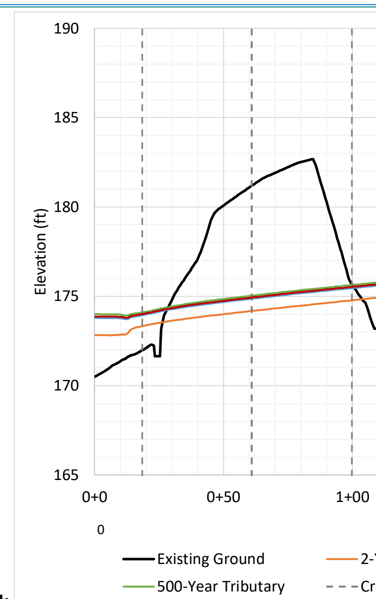

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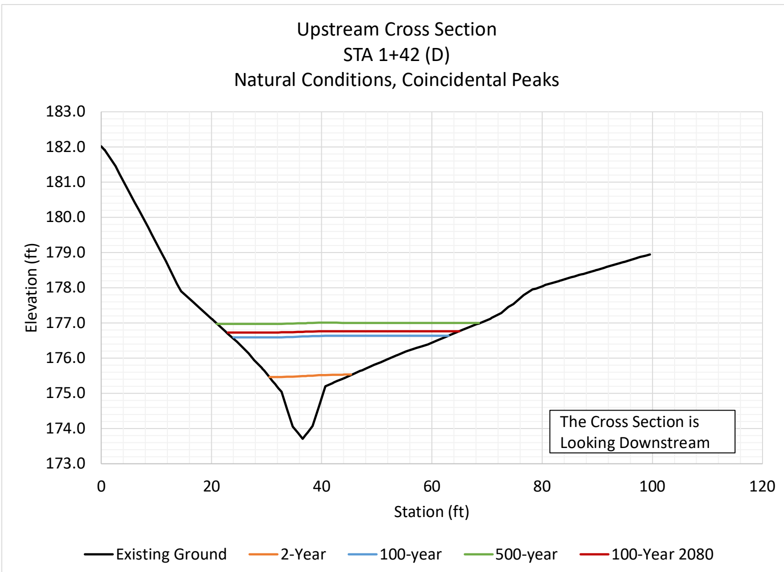


Figure 41: Typical upstream natural channel cross section (facing downstream), coincident peaks

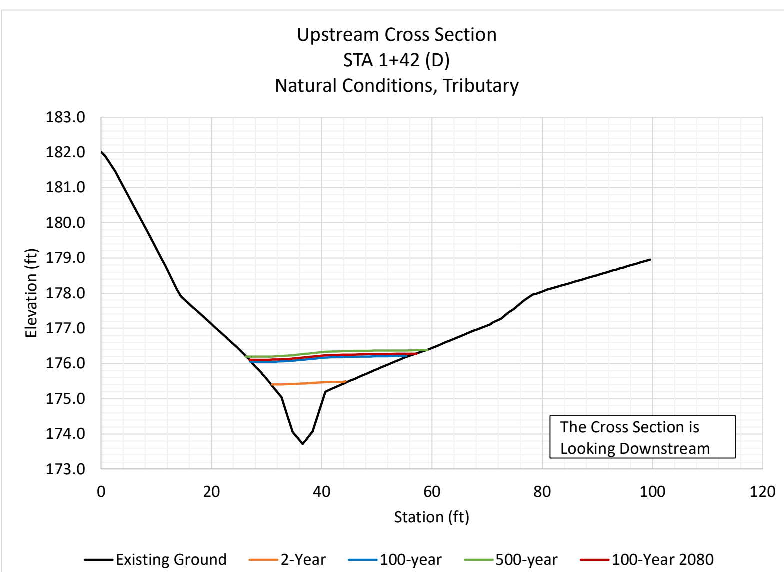
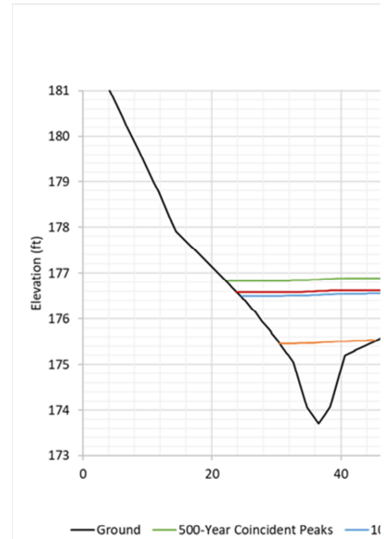


Figure 42: Typical upstream natural channel cross section (facing downstream), tributary only



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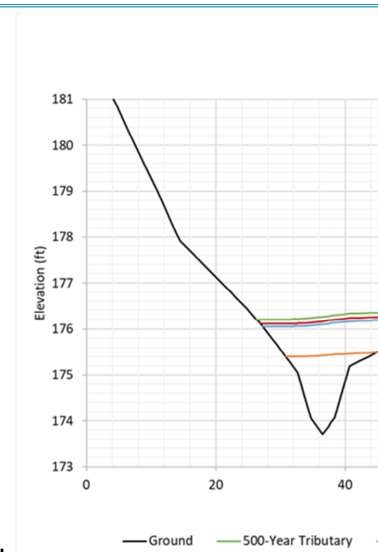

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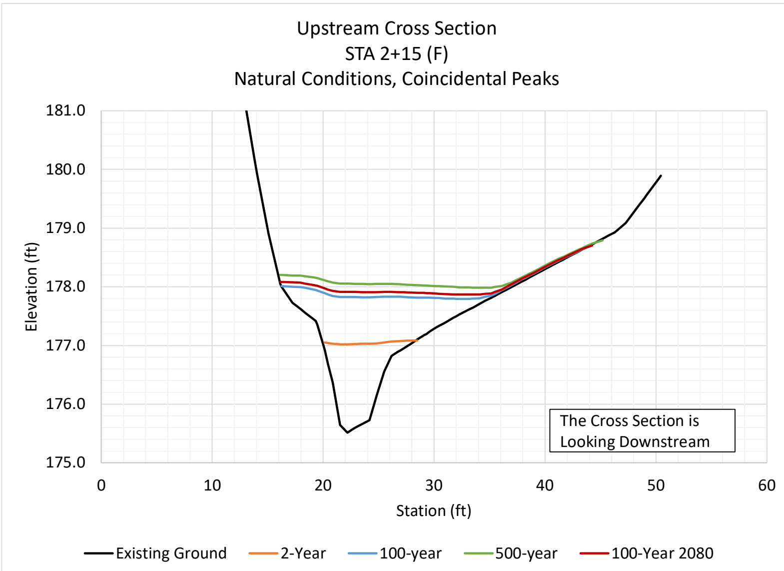

Figure 43: Typical upstream natural channel cross section (facing downstream), coincident peaks

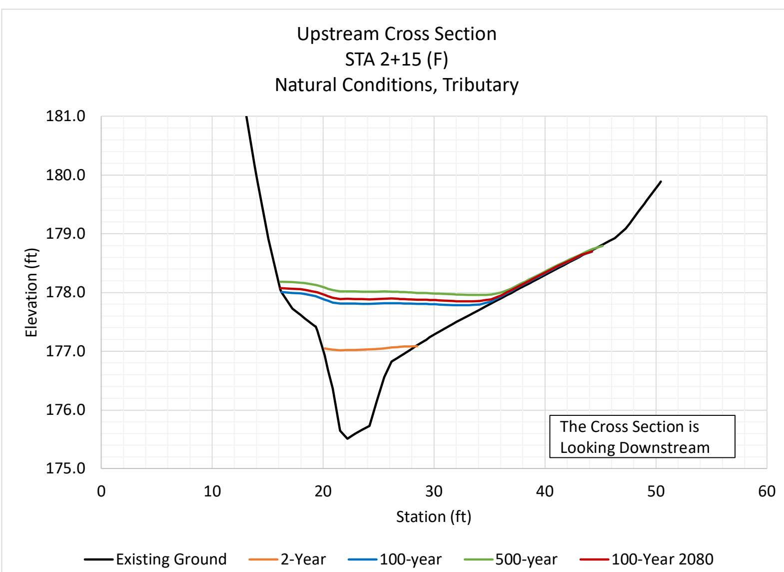

Figure 44: Typical upstream natural channel cross section (facing downstream), tributary only

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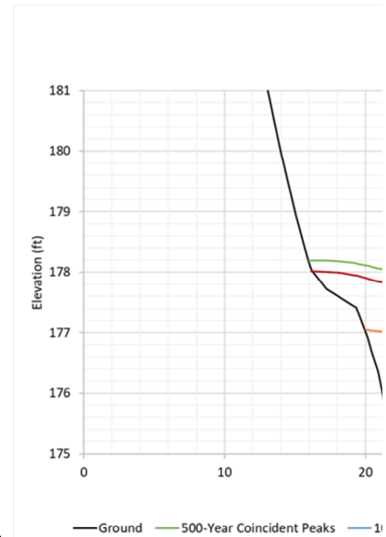

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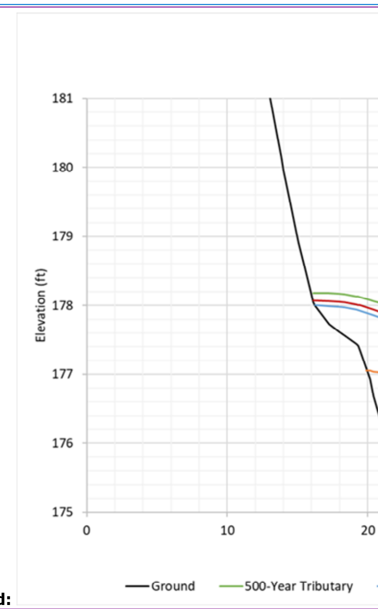

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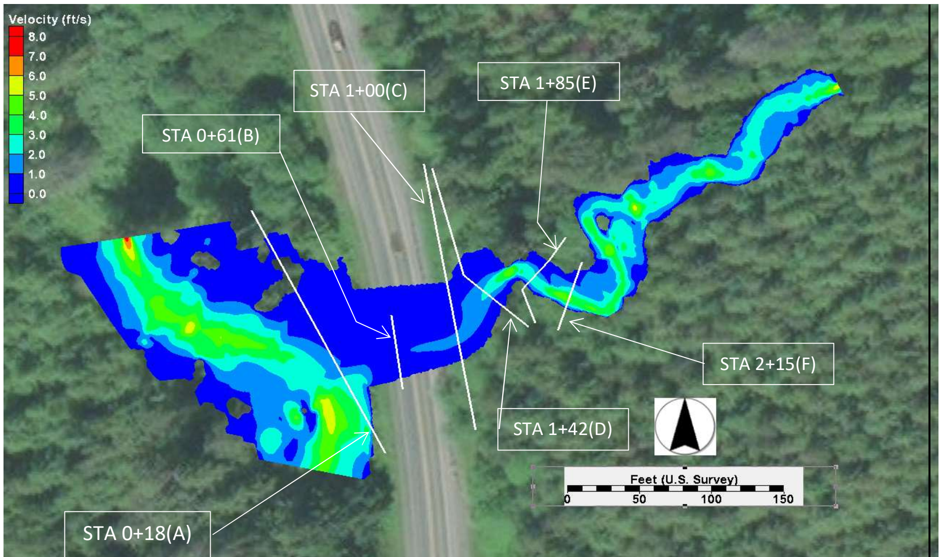

Figure 45: Natural-conditions predicted velocity map with cross-section locations for present day 100-year coincident peaks simulation

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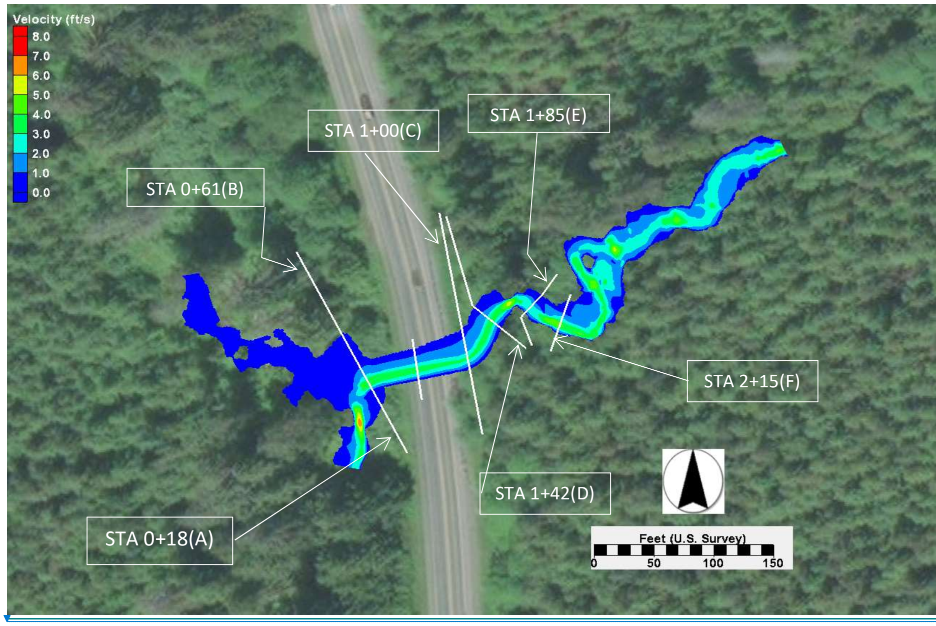

Figure 46: Natural-conditions predicted velocity map with cross-section locations for the present day 100-year tributary simulation

4.4 Proposed Channel Design

This section describes the development of the proposed channel cross-section and layout design.

4.4.1 *Floodplain Utilization Ratio*

The floodplain utilization ratio (FUR) is determined by dividing the flood-prone width (FPW) by the BFW. A ratio under 3.0 is considered a confined channel, and above 3.0 is an unconfined channel. The FPW was determined from the modeled natural conditions 100-year tributary event at four cross sections upstream of the crossing. The FPW values were each divided by the design BFW of 9.0 feet to compute the FUR. Table 12 shows each FPW, the calculated FUR, and the average FUR across all cross sections. The average results in a FUR of 2.9; therefore, the channel is confined and a stream simulation design was accordingly developed for this site, which is predicated on emulating reference reach conditions.

It should be noted that the channel downstream of the culvert under backwater control from the West Fork Hoquiam River is unconfined, with floodplain flow controlled by the mainstem.

Table 12: FUR determination

Station	FPW (ft)	FUR
STA 0+61 (B)	26	2.9
STA 1+00 (C)	32	3.5
STA 1+42 (D)	28	3.1

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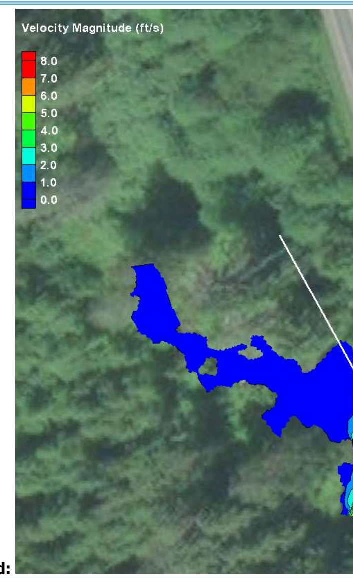

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STA 1+85 (E)	20	2.2
	Average	2.9

4.4.2 *Channel Planform and Shape*

The WCDG prefers in a stream simulation design that the channel planform and cross-section shape mimic conditions within a reference reach (Barnard et al. 2013). The proposed channel cross-section shape accordingly emulates WSDOT's typical reference channel-based design (Figure 47), with the relative location of the thalweg across the section varying depending on whether the channel is straight or curving. A meandering planform is proposed within the replacement structure to increase total roughness within the culvert and accordingly reduce velocities, and to provide greater habitat complexity.

The bottom cross-section shape of the reference-based channel has a bottom side slope of 5 horizontal (H):1 vertical (V) between the thalweg and bank toes, 2H:1V streambank slopes, and an overbank terrace at roughly a 15H:1V slope to create a channel similar to the observed existing channel shape. It is expected that the bottom shape will continue to adjust naturally during high water, where the proposed shape provides a reasonable starting point for subsequent channel shape evolution and bank stability will be provided via bioengineering design. Overall, the proposed design cross-section shape approximates reference reach conditions (Figure 48).

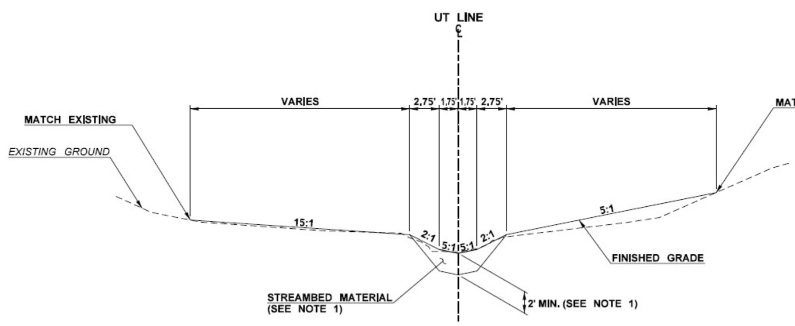

Figure 47: Reference channel-based design cross section for outside the culvert footprint

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Outside of the replacement structure, the proposed channel cross-section profile generally follows WSDOT's typical reference channel-based design (Figure 45), with the relative location of the thalweg across the section varying depending on whether the channel is straight or curving. The bottom cross-section profile of the reference-based channel has a bottom side slope of 5 horizontal (H):1 vertical (V) between the thalweg and bank toes, 2H:1V streambank slopes, and an overbank terrace at roughly a 15H:1V slope to create a channel similar to the observed existing channel shape. It is expected that the bottom profile will continue to adjust naturally during high water, where the proposed profile provides a reasonable starting point for subsequent channel profile evolution and bank stability will be provided via bioengineering design. Overall, the proposed design cross-section profile approximates reference reach conditions (Figure 46).¶
As discussed above, however, the proposed design cross section within the structure reflects the constraint posed by side slope stability of an unarmored, non-cohesive streambed, and the geomorphic observation that gravel supply rates to the cul ... [13]

Moved down [3]: In addition, where flood flows are competent to mobilize the streambed substrate in a culvert with steeper gradients such as the project site, there is a risk of a headcut forming at the upstream end of the excavated reach as the streambed regrades to a lower gradient both stream- and cross-

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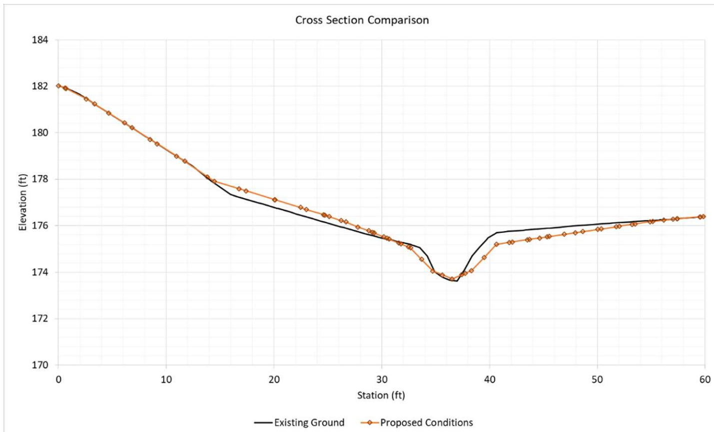

Figure 48: Comparison of design cross-section with a representative cross-section outside of the replacement structure footprint

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Bioengineering methods can be implemented towards long term stability of the channel cross-section shape and planform outside the culvert. This is not necessarily the case for under replacement structures that are not long, high bridges, however, as is the case for this site where bank stabilizing vegetation typically will not grow and use of large woody material presents special constructability and maintenance problems. Except for very slow, low gradient channels, it is not possible to preserve a steep side slope without vegetation or specifying a particle size that is markedly larger than that typically specified for an alluvial, mobile streambed and is stable under all flows. For the project stream's gradient, side slope stability equations predict that gravel and cobble substrates will mobilize readily unless the cross-section is relatively flat (see Appendix D). Indeed, this is a primary reason why the profiles of constructed stream simulation designs using gravel and cobble tend to wash out and flatten within the first winter season of high flows. In the case of the project stream, calculations based on the hydraulic model predictions of shear stress and velocity during the 100-year flood peak indicate that even a flat bottom cross-section is not stable when the streambed grain size distribution approximates the sieve sample in Table 4 (see Section 5).

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However, the stream simulation design methodology as stipulated in WAC 220-660-190 is based on emulating a mobile bed reference channel morphology and substrate within the structure as well as outside, irrespective of future evolution of the channel cross-section profile. Given that vegetative stabilization is not feasible for this site, and measures to fix the bed in place are inconsistent with the stream simulation design approach, an alternate method is needed to counter flattening of the bed and preserve a meander morphology. Accordingly, the proposed design consists of a cobble surface armor layer placed on top of each meander bar. The cobble is sized to become partially mobile around the 100-year flood level so that material can adjust as needed yet remain within the culvert with the goal of preserving a meandering planform. The design rationale for specifying the grain size distribution of the

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cobble armor layer is described in greater detail Section 5. In general, the following considerations influenced design of the meander bars:

- The meander bars should be composed of a surface layer consisting of coarser cobble material that can self-organize into a stable, natural arrangement under a 100-year flood flow to avoid flattening out of the cross-section profile. Specific criteria include:
  - The grain size distribution of the material should reflect a critical dimensionless shear stress between 0.03 and 0.06, and closer to 0.03 in order to maintain a riffle form (e.g., Pasternack and Brown 2013; see Section 5.1).
  - The thickness of the surface layer should be at least twice the D_{90} of the cobble material, which is the general expected disturbance depth of a coarse bedded surface layer that is disturbed by mobilizing flows (cf. Wilcock et al. 1996; DeVries 2002). It is not necessary to extend this material all the way down to the bottom of the streambed fill because it is designed to adjust with streambed regrading but generally remain at the same location within the culvert. However, in cases where an additional safety factor is desired, the layer can extend down to the depth of the constructed thalweg.
- The design goal for spacing of the bars should reflect a maximum head drop over a naturally formed riffle, rather than emulating a classic geomorphic pool-riffle spacing criterion, given the meander bars are intended to be effectively stable. To reduce the potential for re-grading to adversely affect upstream swimming ability, the head drop between bar centerlines (across the channel) should be below typical criteria for juvenile salmonids to accommodate upstream movements of other native fish species. For this site, a head drop of 3 inches between bar apices was selected based on professional judgment, where the drop is expected to be across a naturally formed riffle after the streambed is reworked by floods, assuming worst case regrading occurs such that the gradient of the streambed between bar apices becomes flatter.
- The bar material should not protrude above the design surface, where the intervening material is designed to be in flush with the edge of the bar material and is sized to be stable on the prevailing stream gradient and side slope.
- Additionally, stable habitat boulders (typically 2-man or larger; WSDOT specification 9-03.11(4)) can be placed embedded into the streambed surface to increase channel roughness, which helps slow velocities within the structure and provide hydraulic sheltering for fish during high flows.

The corresponding proposed design is depicted schematically in Figure 49.

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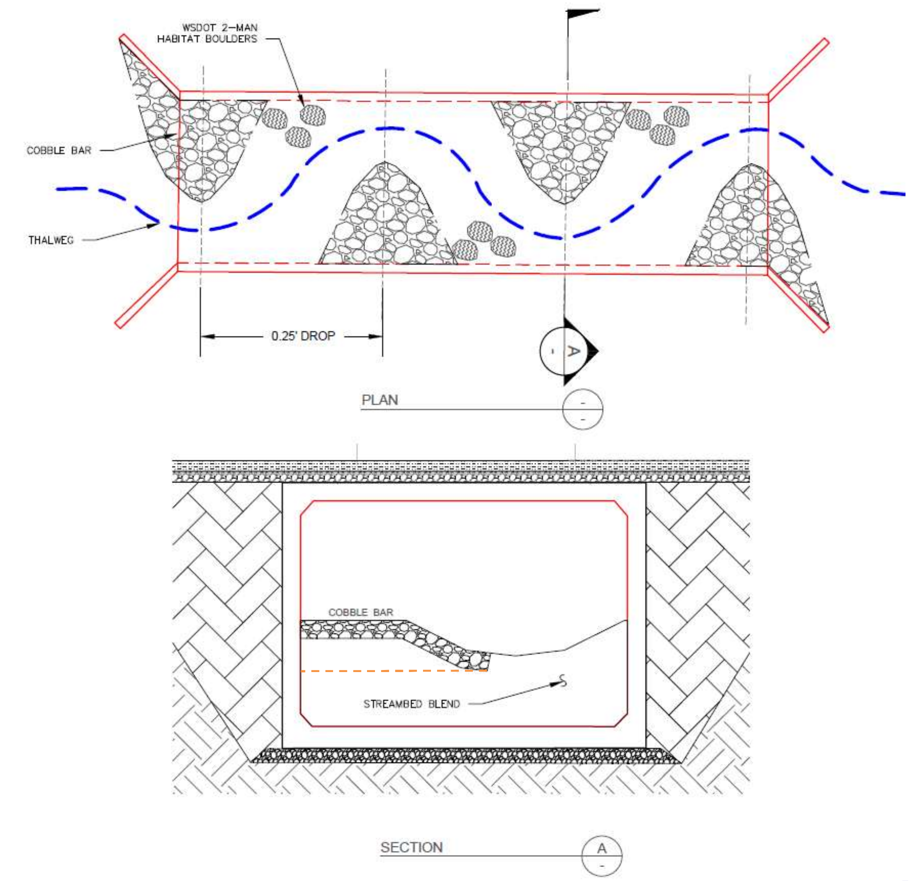

Figure 49: Schematic of proposed channel planform (top) and cross-section (bottom) layout inside the culvert. If there is concern of future loss of bar material to downstream, the thickness of the cobble layer can be increased to the dashed line.

4.4.3 *Channel Alignment*

The proposed project stream alignment deviates from the existing alignment to result in requiring a shorter culvert. Because the existing alignment has several sharp meanders in the vicinity of the culvert inlet, the proposed alignment was modified to result in bends with reduced radii of curvature, which can reduce erosion risk. The new alignment was determined by removing the channelized reach downstream of the existing culvert, meeting slope ratio requirements, and limiting impacts to the existing stream. Length of grading was based on meeting the slope ratio and limited grading extents, and tie-in points were chosen at locations that tie in with the existing upstream and downstream grade.

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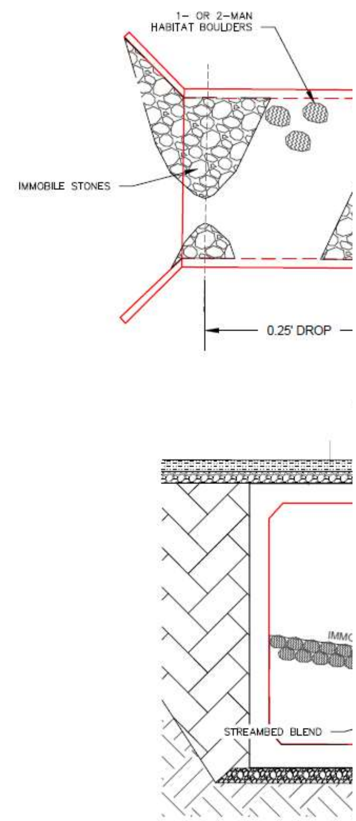

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The proposed channel alignment and grading extents are illustrated in design drawings provided in Appendix E.

4.4.4 *Channel Gradient*

The WCDG recommends that the proposed culvert bed gradient not be more than 25 percent steeper than the existing stream gradient upstream of the crossing (WCDG Equation 3.1). The proposed channel is graded between approximately 9 feet downstream of the culvert outlet and 50 feet upstream of the culvert inlet, with a gradient of approximately 1.5 percent, intermediate to the steeper upstream gradient in the project stream and the lower downstream gradient of the West Fork Hoquiam River. The alignment and grading extents are illustrated in design drawings provided in Appendix E. The proposed channel gradient is approximately 83 percent of the average reference reach gradient of 1.8 percent upstream. This slope ratio is under the WCDG's recommended maximum value of 1.25 (Barnard et al. 2013).

4.5 Design Methodology

The proposed culvert hydraulic design was developed using the 2013 *Water Crossing Design Guidelines* (Barnard et al. 2013) and the WSDOT *Hydraulics Manual* (WSDOT 2019). Using the guidance in these two documents, the stream simulation design method was determined to be the most appropriate at this crossing because the channel is confined upstream with a calculated FUR less than 3.0, the BFW was determined to be less than 15 feet, the slope ratio is less than 1.25, and there is limited concern for lateral migration.

4.6 Future Conditions: Proposed 13-Foot Minimum Hydraulic Opening

The determination of the proposed minimum hydraulic opening width is described in section 4.7. A 13-foot opening was modeled as an open channel with 9 ft BFW channel and floodplain, with vertical side walls. The channel bankfull cross-section profile matched the shape in Figure 47 both inside and outside the culvert. The resulting hydraulic predictions were used in the analyses to yield conservative design parameters for freeboard and substrate sizing. Locations of the cross sections used to report results for the proposed-conditions hydraulic model are shown in Figure 50. The stationing for each cross section is assigned using the proposed alignment as shown in Figure 51.

The hydraulic model results presented at each cross section include WSEL, depth, velocity, and shear stress as shown in Tables 13 and 14. Most variables are average values along the channel except for the depth as it is reported as a maximum. More detailed hydraulic model results are included in Appendix C. Predicted WSELs are presented along the longitudinal profile for the proposed conditions as shown in Figures 52 and 53. Representative cross-section profiles are shown in Figures 54-57 for the 100-year flood in the channel upstream and in the replacement culvert. Figures 58-61 depict the spatial distribution of velocities during the present day and anticipated future 100-year flood peaks from both downstream boundary condition scenarios.

Based on the tributary and coincident scenarios for the 2-year, 100-year, and 500-year events, there is significantly less backwater upstream of the crossing in the existing conditions simulations compared with the proposed minimum hydraulic opening. In the 100-year tributary simulation, very little hydraulic

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The starting point for the design of all WSDOT structures is Equation 3.2 of the WCDG, rounded up to the nearest whole foot. For this crossing, a minimum hydraulic opening of 13 feet was determined to be the minimum starting point. This value was based on a design BFW of 9.0 feet per concurrence of the co-managers and the Stream Team.

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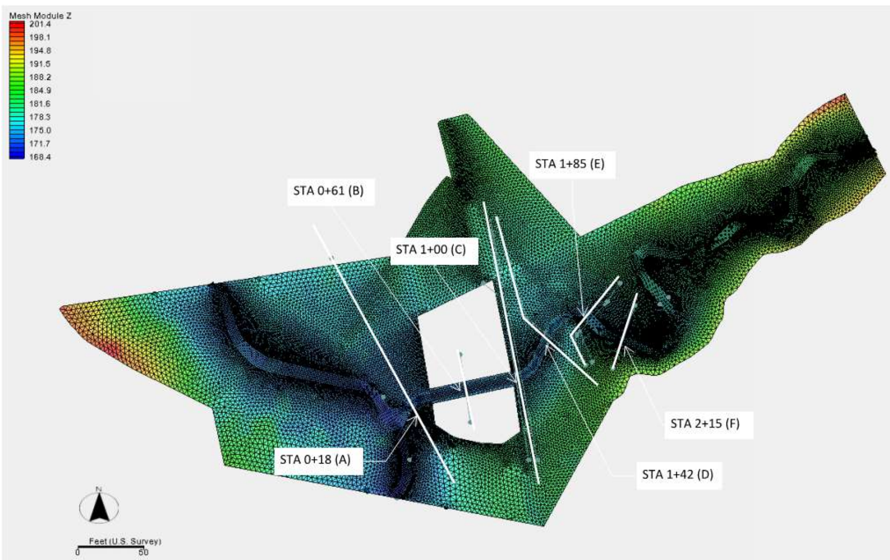

Figure 50: Locations of cross sections used for reporting results of proposed PHD simulations

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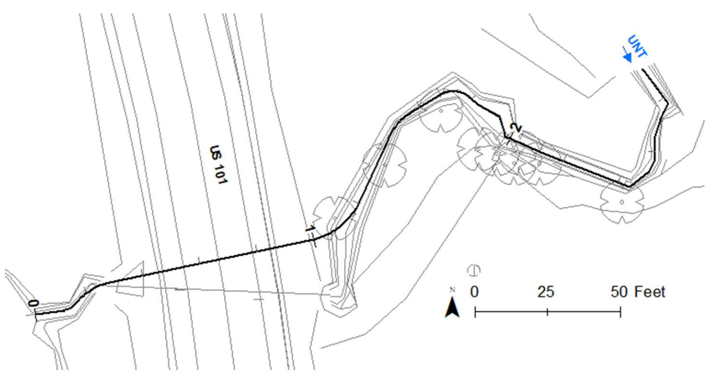

Figure 51: Longitudinal profile stationing for proposed conditions

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Table 13: Average main channel hydraulic results for proposed conditions upstream and downstream of structure (C=coincident peaks, T=tributary only)

Hydraulic parameter	Cross section Sta	2-year (C)	100-year (C)	2080 100-year (C)	500-year (C)	2-year (T)	100-year (T)	2080 100-year (T)	500-year (T)
Average WSEL (ft)	0+18 (A)	174.9	176.3	176.4	176.6	173.3	173.9	173.9	174.0
	0+61 (B)*	174.9	176.3	176.4	176.6	173.8	174.4	174.5	174.6
	1+00 (C)	175.0	176.3	176.5	176.7	174.5	175.2	175.3	175.4
	1+42 (D)	175.4	176.5	176.6	176.8	175.4	176.0	176.1	176.2
	1+85 (E)	176.1	177.2	177.3	177.6	176.1	177.2	177.3	177.5
	2+15 (F)	177.0	177.8	177.8	178.0	177.0	177.7	177.8	177.9
Maximum water depth (ft)	0+18 (A)	3.1	4.5	4.6	4.8	1.5	2.0	2.1	2.2
	0+61 (B)*	2.5	3.8	4.0	4.2	1.3	2.0	2.0	2.1
	1+00 (C)	1.9	3.3	3.4	3.6	1.4	2.1	2.2	2.3
	1+42 (D)	1.7	2.8	2.9	3.1	1.6	2.3	2.4	2.5
	1+85 (E)	2.1	3.2	3.3	3.5	2.1	3.1	3.2	3.4
	2+15 (F)	1.5	2.2	2.3	2.4	1.5	2.2	2.3	2.4
Average velocity magnitude (ft/s)	0+18 (A)	0.8	1.3	1.4	1.4	2.7	3.9	3.9	4.0
	0+61 (B)*	1.2	1.6	1.7	1.8	3.0	4.6	4.7	4.9
	1+00 (C)	1.9	1.9	2.0	2.0	2.8	3.9	4.0	4.1
	1+42 (D)	2.3	2.3	2.3	2.3	2.4	3.3	3.4	3.5
	1+85 (E)	1.6	2.4	2.4	2.5	1.6	2.4	2.5	2.6
	2+15 (F)	3.5	4.4	4.5	4.5	3.5	4.4	4.5	4.6
Average shear stress (lb/SF)	0+18 (A)	0.1	0.2	0.2	0.2	1.4	2.2	2.2	2.3
	0+61 (B)*	0.1	0.1	0.1	0.1	0.6	0.9	1.0	1.1
	1+00 (C)	0.5	0.4	0.5	0.5	1.5	2.2	2.2	2.3
	1+42 (D)	0.8	0.7	0.7	0.7	0.9	1.5	1.5	1.6
	1+85 (E)	0.4	0.7	0.7	0.7	0.4	0.7	0.8	0.8
	2+15 (F)	2.1	2.6	2.7	2.7	2.1	2.7	2.7	2.7

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Table 14: Proposed-conditions average velocities predicted for 100-year flood over floodplains and in main channel at select cross sections

Location	Coincident Peaks 100-year Average Velocities (ft/s)			Tributary Only 100-year Average Velocities (ft/s)		
	LOB [a]	Main ch.	ROB [a]	LOB [a]	Main ch.	ROB [a]
STA 0+18 (A)	2.9	1.3	0.5	0.4	3.9	0.6
STA 0+61 (B)	1.6	1.6	1.3	2.3	4.6	2.5
STA 1+00 (C)	0.6	1.9	0.5	1.7	3.9	1.0
STA 1+42 (D)	0.5	2.3	0.8	0.9	3.3	1.1
STA 1+85 (E)	1.4	2.4	0.5	1.4	2.4	0.5
STA 2+15 (F)	2.0	4.4	1.1	2.0	4.4	1.1

b. Right overbank (ROB)/left overbank (LOB) locations determined from the top of the bank

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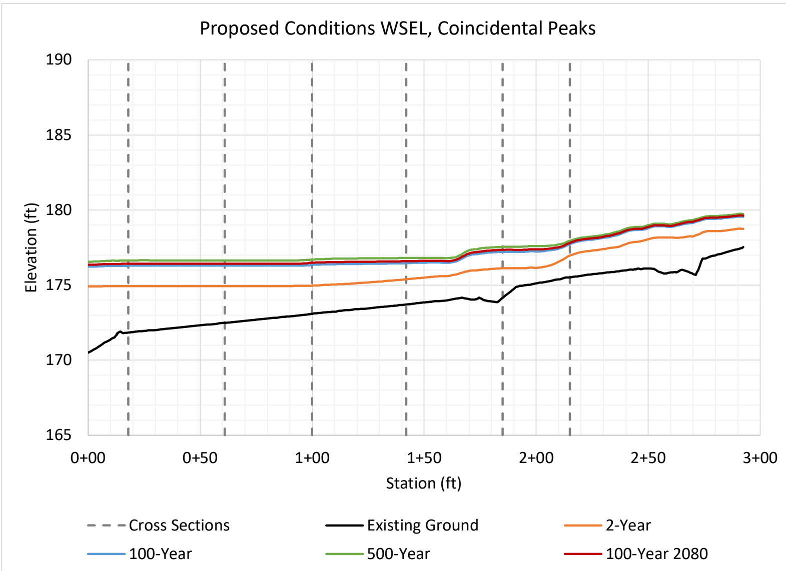

Figure 52: Proposed-conditions water surface profiles, coincident peaks

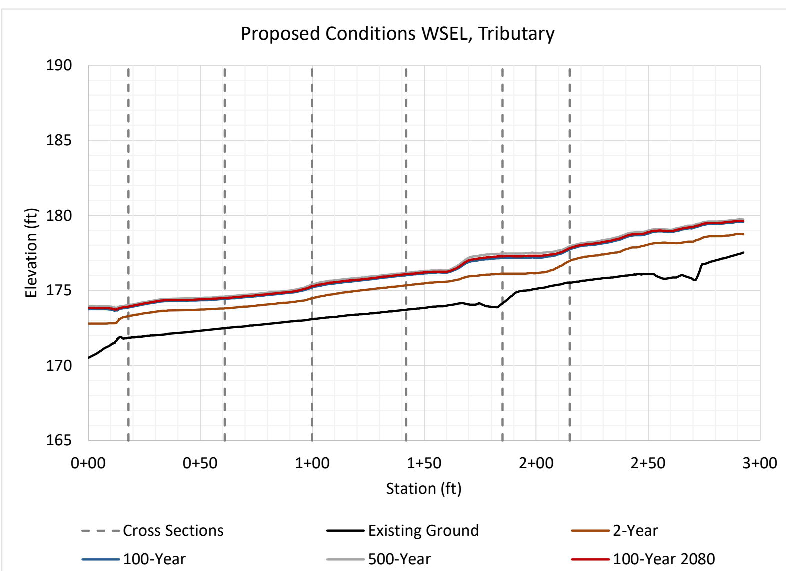

Figure 53: Proposed-conditions water surface profiles, tributary only

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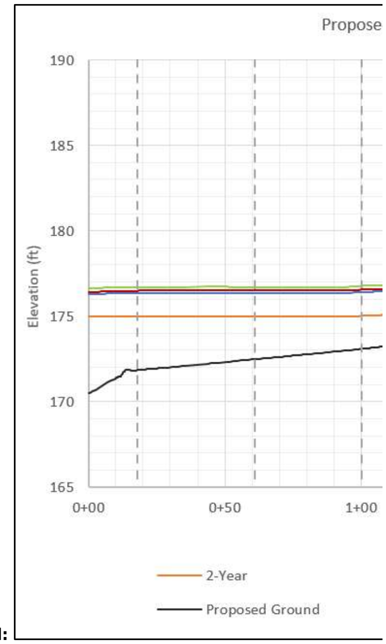

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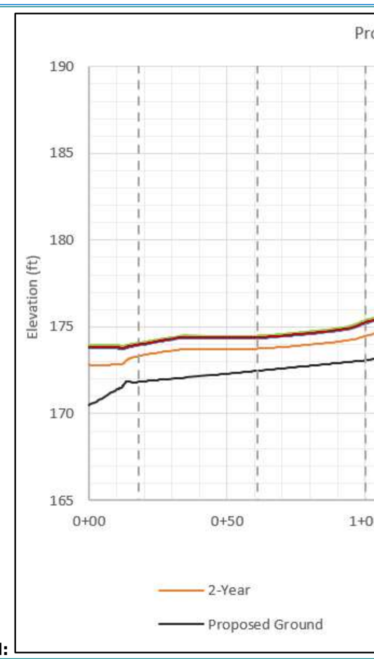

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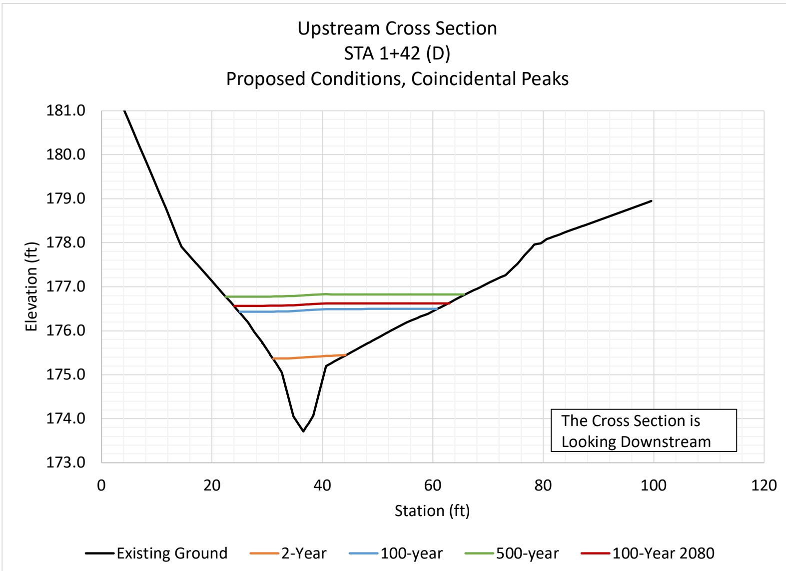

Figure 54: Typical section upstream of proposed structure (facing downstream), coincident peaks

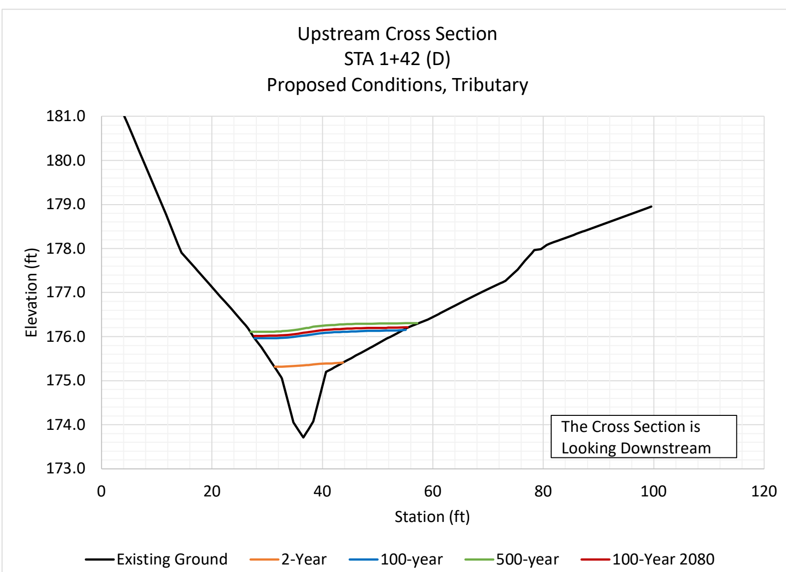

Figure 55: Typical section upstream of proposed structure (facing downstream), tributary only

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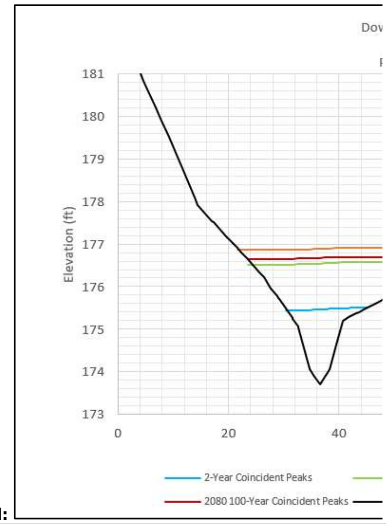

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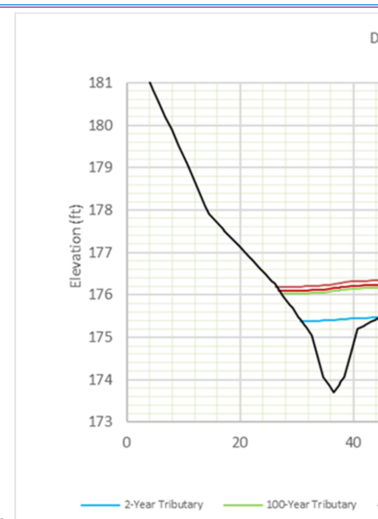

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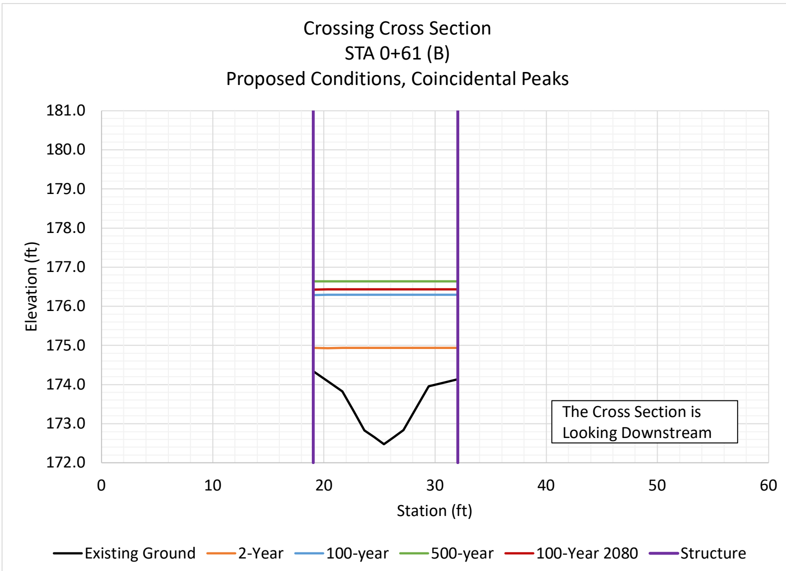

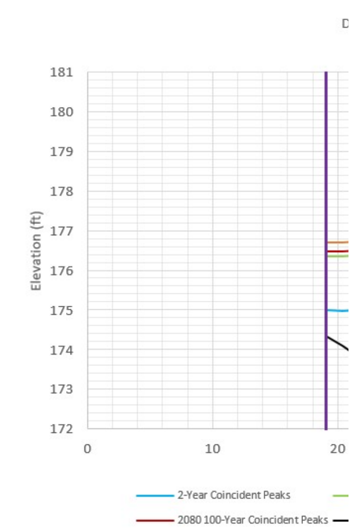

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Figure 56: Typical section within proposed structure (facing downstream), coincident peaks

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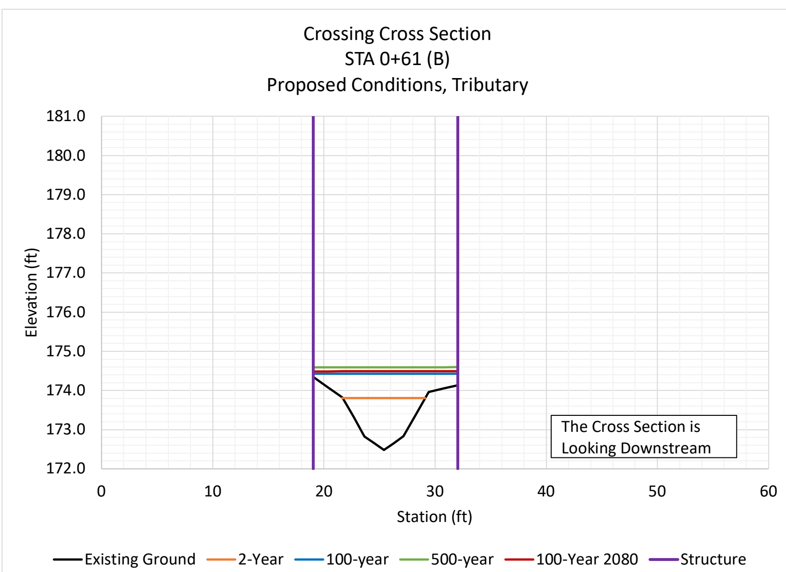

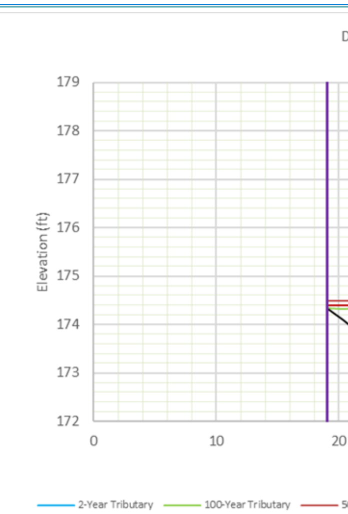

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Figure 57: Typical section within proposed structure (facing downstream), tributary only

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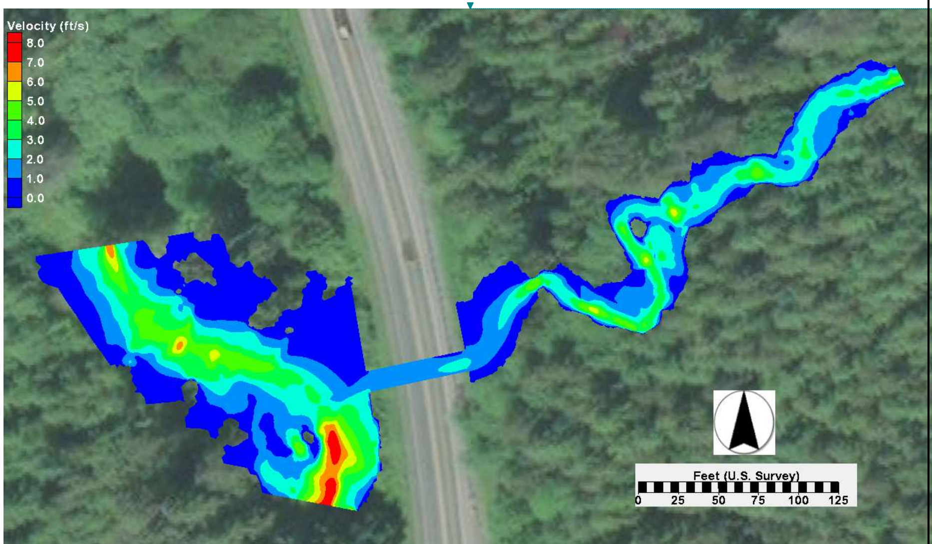

Figure 58: Proposed-conditions predicted 100-year velocity map for coincident peaks scenario

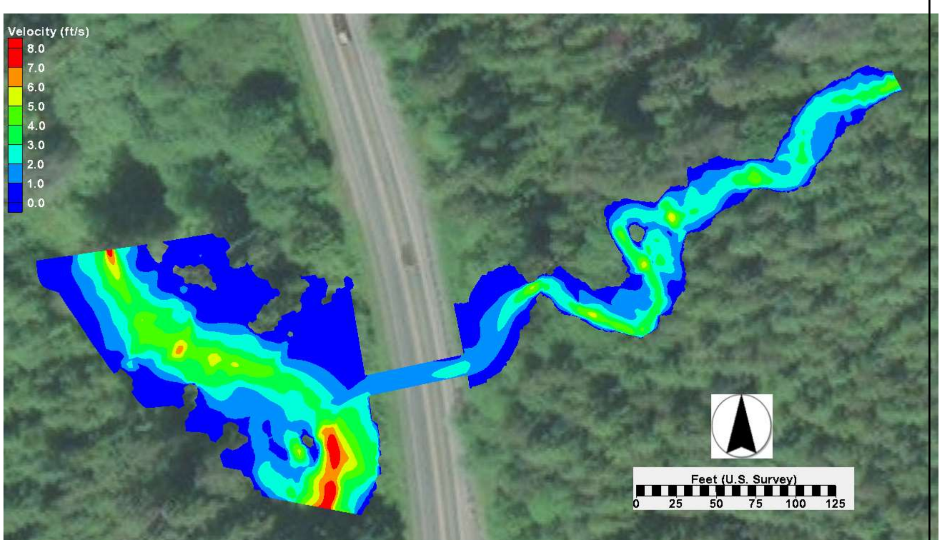

Figure 59: Proposed-conditions predicted 2080 100-year velocity map for coincident peaks scenario

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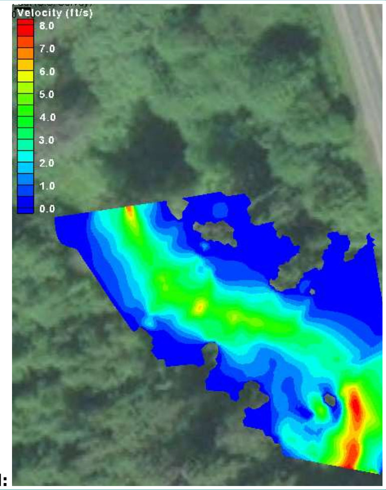

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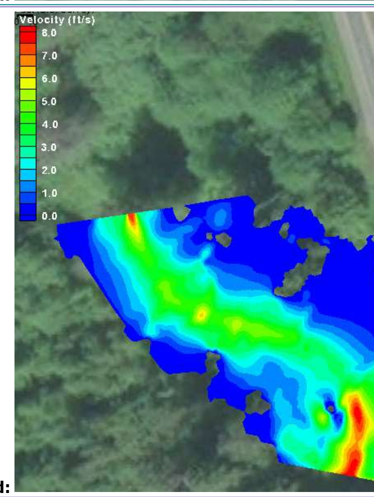

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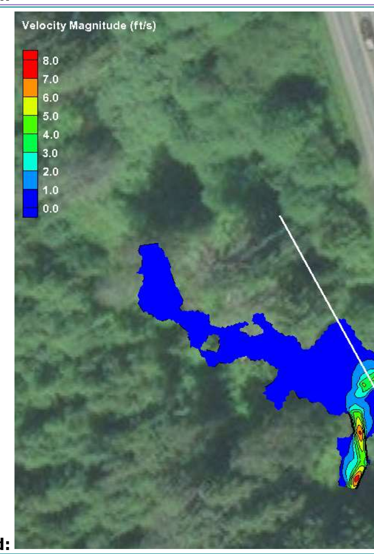

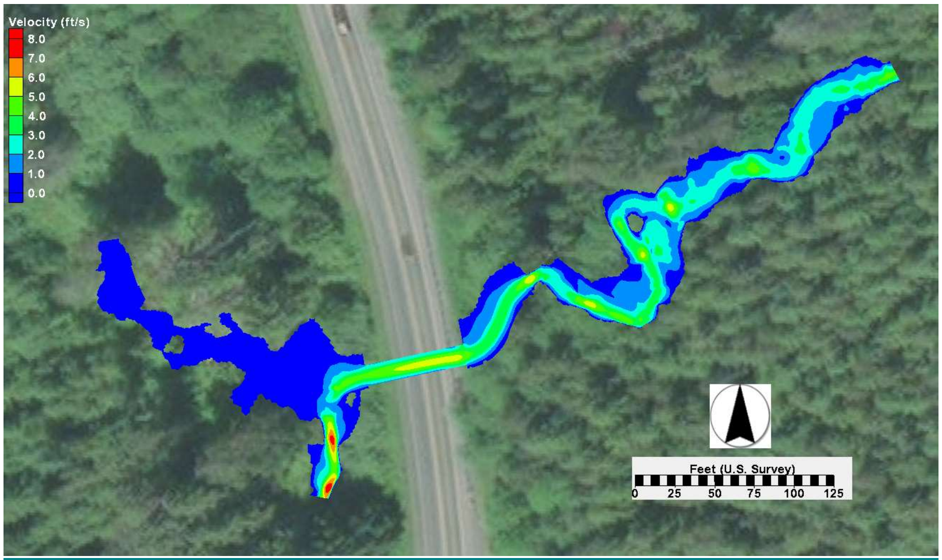

Figure 60: Proposed-conditions predicted 100-year velocity map for tributary only scenario

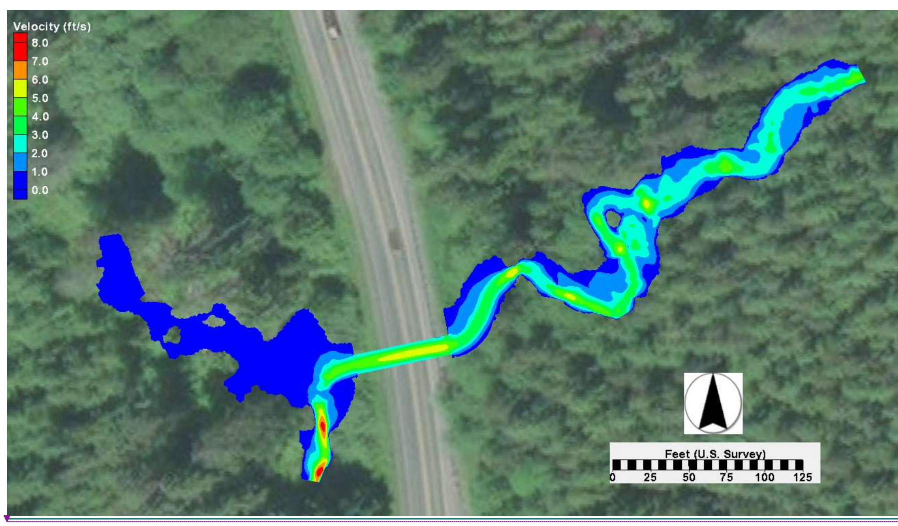

Figure 61: Proposed-conditions predicted 2080 100-year velocity map for tributary only scenario

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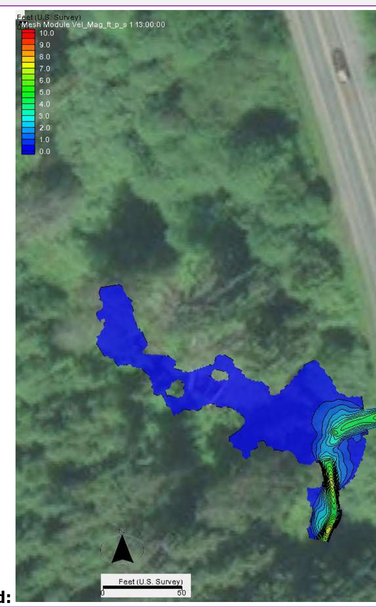

4.7 Water Crossing Design

Water crossing design parameters includes structure type, minimum hydraulic opening width and length, and freeboard requirements.

4.7.1 *Structure Type*

A concrete box culvert is under consideration presently for this site.

4.7.2 *Minimum Hydraulic Opening Width and Length*

The hydraulic opening is defined as the width perpendicular to the creek beneath the proposed structure that is necessary to convey the design flow and allow for natural geomorphic processes. The hydraulic opening assumes vertical walls at the edge of the minimum hydraulic opening width unless otherwise specified. The starting point for the design of WSDOT structures is Equation 3.2 of the WCDG (Barnard et al. 2013), rounded up to the nearest whole foot. For this crossing, a minimum hydraulic opening of 13 feet was determined to be the minimum starting point. This value was based on a design BFW of 9.0 feet per concurrence of the co-managers and the Stream Team.

The present day 100-year and projected 2080 100-year flood magnitudes were simulated for the proposed conditions to evaluate predicted velocities within a 13 feet wide structure. Initial calculations performed during development of the draft PHD were based on assuming a similar roughness inside the replacement structure as in the natural channel, which resulted in predicting velocities that may be lower than would actually occur. As discussed in Section 4.4.2, the roughness in the project stream should not be expected to be similar inside the culvert as outside. As a consequence, the calculated velocity will be higher than when assuming similar roughness values throughout, irrespective of hydraulic opening width. Updated main channel velocity predictions are summarized for both the tributary only and coincident peaks scenarios in Table 15. The tributary only scenario is associated with velocities that are relatively high, whereas the coincident peaks scenario is associated with relatively low velocities at the 100 year flood peak. However, neither scenario is likely. It is more likely that the West Fork Hoquiam River would be at an intermediate flood level when the project stream experiences a 100-year flood, and so a separate model run was performed assuming a concurrent 10-year flood in the mainstem. The resulting velocity prediction is comparable to the coincident peaks scenario, and the magnitude of the velocity within the 13 feet wide structure is less than predicted in the natural channel upstream (Table 15; cf. Appendix C). The magnitude is also less than that estimated to be required to scour out the native gravel grain size distribution (cf. Isbash mobility relation in USACE 1994, Table 4).

A separate check was performed to evaluate if widening the structure would reduce the tributary only velocity predictions, where an opening of 18 feet was also simulated. Predicted water surface elevations were similar for the two widths (Figure 62), with corresponding similar velocities. This indicates that a wider structure opening would not bring the velocity down significantly for the tributary only scenario. Consequently, a 13 feet wide hydraulic opening was considered sufficient for this site.

The proposed structure (Appendix E) is approximately 53 feet in length, which is within the WCDG's maximum length:width ratio criterion of 10 for a stream simulation design. The ultimate length will be confirmed at a later stage of design.

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Table 15: Predicted main channel velocities within 13 feet and 18 feet wide structures

Simulation	Velocity in 13 Feet Wide Structure (ft/s)	Velocity in 18 Feet Wide Structure (ft/s)
Tributary Only: 100-year	4.6	4.6
Tributary Only: 2080 100-year	4.7	4.7
Coincident Peaks: 100-year	1.6	1.3
Coincident Peaks: 2080 100-year	1.7	1.4
Tributary 100-year, W Fk Hoquiam 10-Year	1.9	Not simulated

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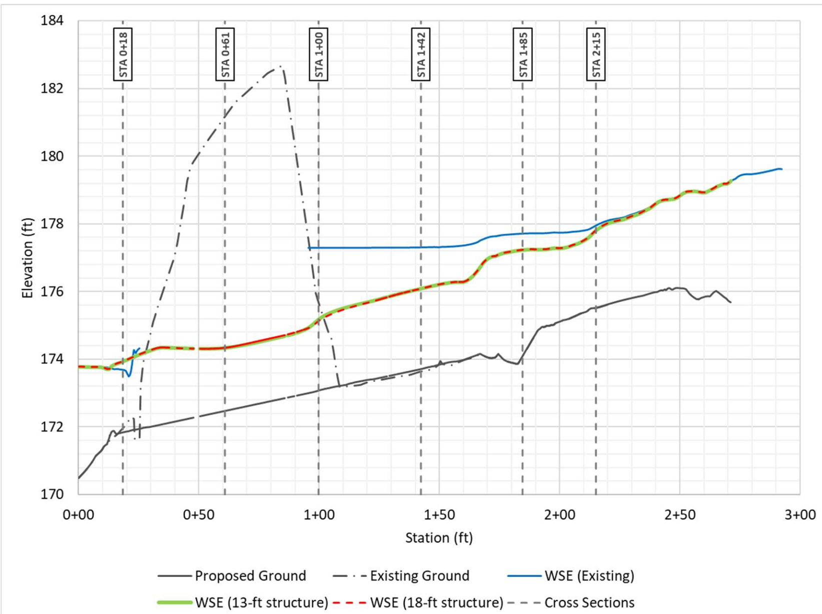

Figure 62: Proposed-conditions predicted 100-year water surface elevations for 13 feet and 18 feet wide structures, tributary only scenario

4.7.3 *Freeboard*

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Freeboard is necessary to allow the free passage of debris expected to be encountered. The WCDG generally suggests a minimum 2-feet clearance above the 100-year WSEL for streams with a BFW of between 8-15 feet to adequately pass debris (Barnard et al. 2013). WSDOT also desires a minimum vertical clearance between the culvert soffit and the streambed thalweg for maintenance equal to 6 feet. WSDOT is incorporating climate resilience in freeboard, where practicable, and so freeboard was evaluated at both the 100-year WSEL and the projected 2080 100-year WSEL. The hydraulic modeling

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indicates that the maintenance-based goal will exceed the clearance required to meet the 2 feet hydraulic-based criterion associated with the proposed design when constructed.

The evaluation of long-term aggradation and degradation presented in Section 2.8.4 indicated that there is a low likelihood of aggradation at the site, but that if it did occur, it would likely be around 1 feet or less. This can be added to the minimum required freeboard (Table 16).

Table 16: Parameters relevant to freeboard specification for proposed 13 feet wide replacement structure

Parameter	2080 100-Year Coincident Flood Predictions	
	At Inlet	At Outlet
Thalweg elevation (ft)	173.0	172.1
Maximum WSEL (ft)	175.2	174.4
Minimum low chord elevation to provide 2 feet of freeboard (ft)	177.2	176.4
Minimum low chord elevation to provide 6 feet maintenance access (ft)	179.0	178.1
Minimum low chord elevation to provide 2 feet of freeboard, without future aggradation (ft)	178.2	177.4
Recommended low chord elevation, with future aggradation (ft)	179.0	178.1

4.7.3.1 Past Maintenance Records
No maintenance problems related to flooding have been recorded by WSDOT for this crossing.

4.7.3.2 Wood and Sediment Supply
The contributing basin is predominantly forested with large trees present that are a potential source of LWM. Based upon the flow velocities, depths of flow, and BFW of the stream, the potential to transport LWM is low. Further, the overbanks are well vegetated and forested, which further impedes the ability to transport LWM. As described in section 2.8.6, mobile wood pieces in the stream appear to be smaller than 6 inches in diameter and around 7 feet in length, and thus would be expected to clear easily under the proposed 13 feet wide structure with 2 feet of freeboard during the 100-year flood.

4.7.3.3 Flooding
As described in Section 2.3, the site is not located in a FEMA-delineated floodplain. Historical flooding problems have not been noted by WSDOT for this site. The proposed hydraulic opening will increase the capacity of the crossing and significantly reduce the backwater in comparison to the existing conditions.

4.7.3.4 Future Corridor Plans
There are currently no long-term plans to improve U.S. 101 through this corridor.

4.7.3.5 Impacts
It is not anticipated that the road level will be raised to accommodate the proposed minimum hydraulic opening. A final decision will be made at a later design phase.

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4.7.3.6 Impacts to Fish Life and Habitat

It is expected that the proposed freeboard of 2 feet will result in no substantial impacts to fish life and habitat.

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5 Streambed Design

The streambed design considered the local characteristic grain size distribution (GSD) of gravel collected in the sieve sample, standard streambed stability calculations for the proposed channel longitudinal and cross-section profile grading, and requirements of WAC 220-160-190. Two GSDs will be proposed for this site. One grain size distribution is for the streambed mix, which is presented in the section below, and the second is for proposed meander bars within the replacement structure. Partial channel-spanning meander bars are recommended within the proposed structure to encourage natural channel evolution and flow complexity within the constructed channel. The gradation for the proposed meander bars will be designed during the FH phase. In addition, large woody material is proposed to be placed on and over the streambed to provide instream habitat complexity and overhead cover for fish. These two elements of the design are described in separate sections below.

5.1 Bed Material

Where neither of the other two alternative approaches identified in Section 1.0 are indicated for implementation, the injunction requires that the design follow the stream simulation methodology as described in the WAC and WCDG (Barnard et al. 2013). WAC 220-660-190 stipulates that "The median particle size of sediment placed inside the stream-simulation culvert must be approximately twenty percent of the median particle size found in a reference reach of the same stream. The department [WDFW] may approve exceptions if the proposed alternative sediment is appropriate for the circumstances."

For sediment sizing, WSDOT uses the Modified Critical Shear Stress Approach, as described in Appendix E of the 2008 US Forest Service (USFS) Guidelines for all systems under 4 percent and the Unit-Discharge Bed Design as described by the 2013 WCDG for systems greater than 4 percent. Since the grade of the unnamed tributary to Stevens Creek near the US 101 crossing is less than 4 percent, the proposed streambed gradation for the new channel was sized using the Modified Shield's Critical Shear Stress Approach. The mobility analysis performed on the design gradation detailed below uses the 100-year peak flow as the design flow.

The reference reach of this stream is primarily composed of fines, with some isolated gravel patches. A sieve sample was taken during the June 2021 site visit to characterize one of the isolated gravel patches. The findings of this sieve sample are discussed in Section 2.8.3. The proposed streambed mix is designed to be more consistent with the fine sediments and gravelly material found in the reference reach while conforming to the standards put forth by the WAC. The proposed gradation for the unnamed tributary to the West Fork Hoquiam River is 80 percent of Section 9-03.11(1) Streambed Sediment and 20 percent of Section 9-03.11(2) 4-inch Streambed Cobbles. Calculations based on the Modified Shields stress method indicate that every particle size will remain immobile during the 2-year storm event and will be mobile during the 100-year event, thus providing stability within the stream during the low flow events while providing continuity of sediment transport during the higher flow events. Thus, there is a risk that the streambed will regrade without the presence of coarser meander bars. A summary of the observed and proposed overall streambed gradations is presented in Table 17, where the proposed GSD reflects

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Deleted: WSDOT has decided that exceptions should be avoided where possible. In general, what this means is that the streambed substrate grain size distribution is required to have a D_{50} within +/- 20 percent of the native reference substrate. This requirement is not strictly possible to meet at this site, because the reference reach substrate consists primarily of fine material that would not be expected to remain stable if placed within the culvert. There are isolated patches of gravel, so an exception is recommended for this site where the streambed design is instead based on the reference gravel patch grain size distribution with an assessment of risks associated with potential streambed instability. Relevant The proposed bed material gradation was created using standard WSDOT specification material to provide the desired grain size distribution (GSD) within and outside of the culvert. Ccalculations are presented in Appendix D and their implications to the design are summarized below. .

the stable D_{84} size and using WSDOT's standard specification 9-03.11(1). WSDOT's worksheet calculations for the proposed streambed mix are presented in Appendix D. As previously mentioned, the proposed meander bar gradation will be coarser and will be included with the final hydraulic design.

Table 17: Comparison of observed and stable streambed, and proposed stream simulation and meander bar material grain size distributions

	Observed Diameter (in)	Proposed Diameter (in)
D_{16}	0.1	0.1
D_{50}	1.0	0.8
D_{84}	1.9	2.0
D_{90}	2.1	2.3
D_{max}	3.5	3.5

5.2 Channel Complexity

To mimic the natural riverine environment and promote the formation of habitat, the design incorporated placement of key LWM pieces within and across the channel and floodplain. Placement will generally mimic tree fall that is common throughout the reach upstream of the crossing, and embedded wood pieces in the reach downstream to reflect characteristic geomorphic processes in the West Fork Hoquiam River. Complexity is also provided by the meander bar layout proposed in Section 4.4.

5.2.1 *Design Concept*

The total number of key pieces was determined in consideration of criteria presented in Fox and Bolton (2007) and Chapter 10 of the *Hydraulics Manual* (WSDOT 2019), in which WSDOT's recommended key piece density for the project site is 3.4 key pieces and 39.48 cubic yards of volume per 100 feet of channel. A key piece is defined as having a minimum volume of 1.31 cubic yards, which corresponds roughly to a 30 feet long log that has a diameter at breast height (DBH) of 15 inches. WSDOT has established a design goal for this project where the Fox and Bolton (2007) criteria are to be calculated for the total regrade reach length including the culvert, but the pieces of wood are to distribute outside of the culvert. For the proposed total regrade length of 145 feet, the design criteria for this reach are five key pieces with a total volume of 57.2 cubic yards (Appendix H). In small streams, the volume criterion may not always be practically achieved without completely filling the channel and placing a sizeable amount of wood outside of the 2-year flood extent, where smaller diameter logs can achieve the same biological and geomorphic functions. In this design, the primary goal was to exceed the density criterion to get closer to or even meet the volume criterion, while not overloading the stream channel outside of the culvert. Where feasible, wood can be added outside of the regrade extent with the condition that heavy equipment not disturb the channel and floodplain significantly.

A conceptual LWM layout has been developed for the project reach involving a mix of embedded and loose logs with rootwads (Figure 63). The conceptual layout proposes 8 key pieces in a 145-foot-long project reach (including the structure length), which exceeds the number criterion. There is space for this number of pieces, and it allows for smaller pieces of wood in the 14- to 18-inch DBH range, sizes that are comparable to other pieces of wood at the site and gives the contractor flexibility in sourcing

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The SRH-2D model outputs an estimate of shear stress, but the result is based on a 2-D vector adaptation of the uniform flow, wide channel 1-D approximation, and accordingly is a significant over-estimate compared with that derived from velocity profiles (Wilcock 1996; Pasternack et al. 2006; DeVries et al. 2014). . Pasternack and Brown (2013) determined that the type of equation used more closely matches the velocity profile-derived estimate when the velocity is evaluated near the bed. . However, SRH-2D calculates a mean column velocity, but that can be used to estimate near bed shear velocity and thus shear stress. . Two different velocity relations based on the rough form of the law of the wall were evaluated accordingly, and they gave comparable order of magnitude predictions of shear stress (Richards 1982; Pasternack and Brown 2013). . The larger of the two estimates was used to size streambed substrates accordingly using Shields' equation based on D_{50}. . For specifying the overall GSD, guidelines were adopted from Barnard et al. (2013) and USACE (1994). .¶
Following the above approach, the critical Shields stress = 0.045 criterion corresponds approximately to a critical D_{50} = 0.3 inches at the 2-year flood, and 1.4 inches at the 2080 100-year flood ... [27]

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wood. This increased number of variable sized pieces in turn facilitates meeting the net volume target. The mobility and stabilization of LWM will be analyzed in later phases of design. The design involves two log types:

- 3 embedded logs (Type 1) with rootwads to provide habitat and stabilize the constructed left streambank above and below the culvert; the logs downstream are intended to retard meander migration of the West Fork Hoquiam River left bank to reduce potential for incision in the tributary stream. The rootwad will be placed in the low flow channel with a preformed scour hole around it, and the butt end will be buried to sufficient length and depth that additional anchoring is not needed.
- 5 loose, 30+ feet long logs with rootwads, and to the extent possible, with intact branches. One will be placed entirely in the channel (Type 2), two will be placed with rootwad in the channel and tip on the floodplain/adjacent slope (Type 3), and two will span the bankfull channel to promote scouring underneath (Type 4). The type 3 and 4 designs will involve self-ballasting and interlocking with existing trees for stability. The type 2 log will be kept in place by other logs on top, and wedging between streambanks.

The LWM pieces will be placed so they provide habitat features for fish, form pools, and refuge habitat under high flow conditions. Wood stability and the need for anchoring will be assessed at the Final Hydraulic Design (FHD) level. Key pieces will be designed to be anchored by either suitable embedment length/depth, or interlocking with existing trees. To meet WSDOT's total LWM number target, nine (9) additional 12" or larger DBH trees with rootwads would be needed. These smaller pieces would need to be placed loose as directed work, or designed to be embedded in the banks, integrated with the installation of key pieces.

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Risk of fish stranding during summer flow conditions is minimal because proposed grading directs flow back to the main channel and does not promote isolated pools. Similar to a natural stream system, there is the potential for floodplain pools that create some potential to isolate fish that have entered during high flow events.

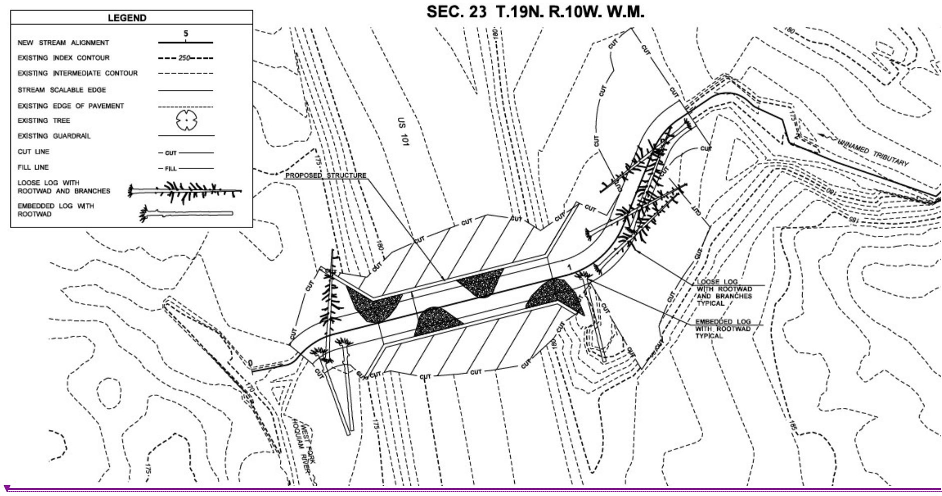

Figure 63: Conceptual layout of key LWM and meander bars for habitat complexity

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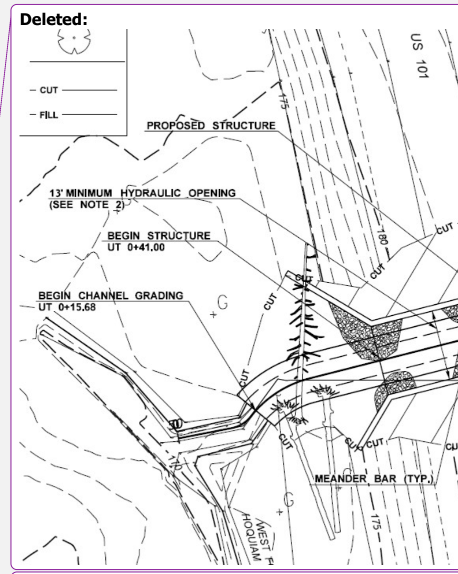

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6 Floodplain Changes

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This project is not within a mapped floodplain. The pre-project and expected post-project conditions were evaluated to determine whether there would be a change in WSEL and floodplain storage.

6.1 Floodplain Storage

Floodplain storage is anticipated to be affected by the proposed structure. The installation of a larger hydraulic opening greatly reduces the amount of backwater and associated peak flow attenuation that was being provided by the smaller, existing culvert. A comparison of pre- and post-project peak flow events was not quantified as the models were run with a steady flow rate specified at the upstream boundary of the model. There is no known existing infrastructure downstream of the crossing that would be potentially impacted, however.

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6.2 Water Surface Elevations

Installation of the proposed structure would reduce the backwater impacts immediately upstream of the existing culvert, resulting in a reduction in WSEL. The WSEL is reduced by as much as 2 feet near the inlet of the existing culvert at the 100-year event as shown in Figures 64 and 65. Figure 66 shows a significant decrease in backwater with the proposed structure alignment, opening, and grading, during the coincident peak 100-Year condition.

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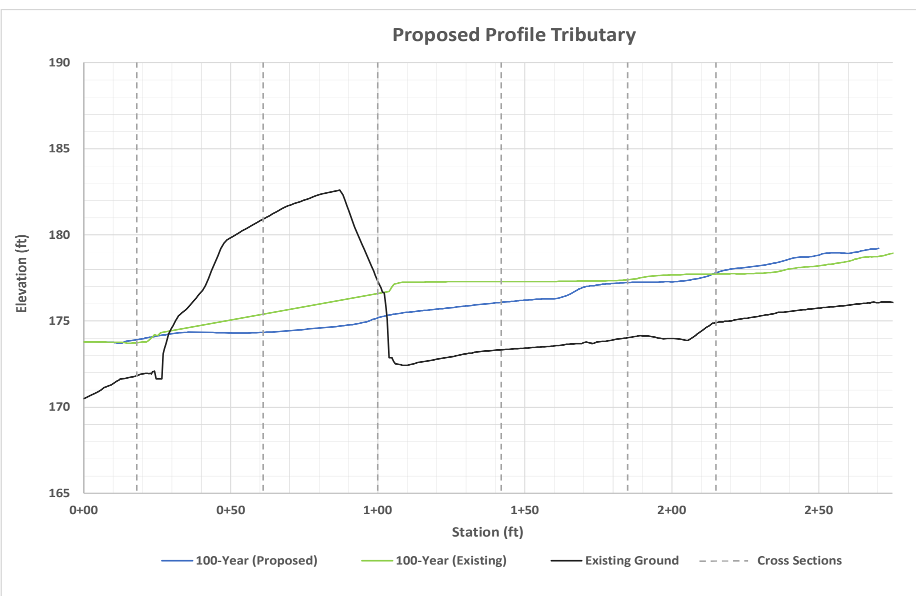

Figure 64: Existing and proposed 100-year water surface profile comparison, tributary only

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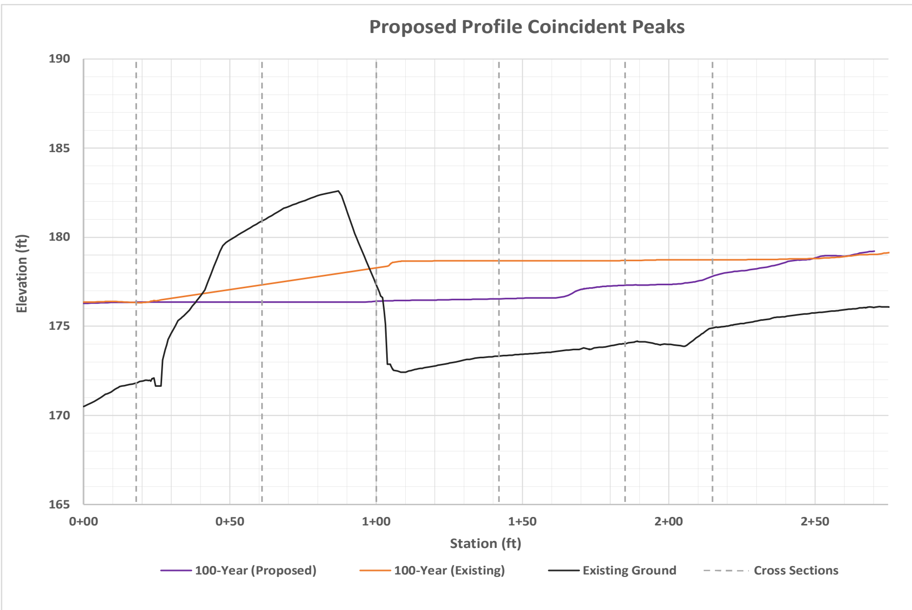

Figure 65: Existing and proposed 100-year water surface profile comparison, coincident peaks

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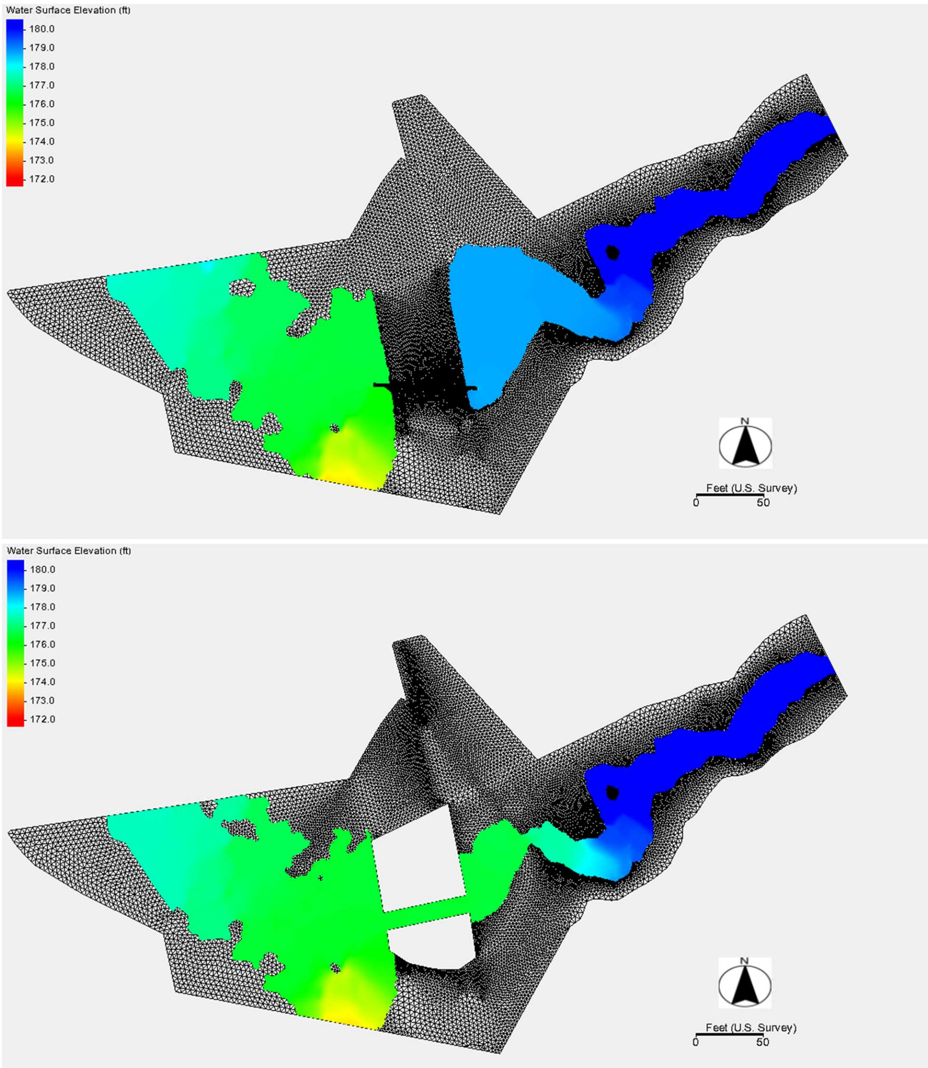

Figure 66: Water surface elevation change from existing (top) to proposed (bottom) conditions

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7 Climate Resilience

WSDOT recognizes climate resilience as a component of the integrity of its structures and approaches the design of bridges and buried structures through a risk-based assessment. For bridges and buried structures, the largest risk to the structures will come from increases in flow. The goal of fish passage projects is to maintain natural channel processes through the life of the structure and maintain passability for all expected life stages and species in a system. At a minimum, climate change is addressed in all bridge, buried structure, and fish passage projects by providing a design in which the foundations or bottoms are not exposed during the 500-year flow event due to long-term degradation or scour. WSDOT also completes a hydraulic model for all water crossings on fish-bearing streams, regardless of design methodology, to ensure that the new structure is appropriately sized. If the velocities through the structure differ greatly from those found elsewhere in the reach, the structure width may be increased above what is required by Equation 3.2 in the WCDG.

General climate change predictions for the broader region are for increased rainfall intensity during winter months, with the caveat that there is great spatial variability in the projections that may preclude downscaling to the project site drainage area, which is relatively small (WSDOT 2011). The project site crossing has been evaluated and determined to be a low risk site based on the Climate Impacts Vulnerability Assessment maps (Figure 67). Based on the determination of this location being a low risk site, no additional climate change design modifications were made. The new structures were designed so their foundations do not become exposed during the 500-year flow event. Also, hydraulic modeling indicated that the flow through the replacement culvert is not predicted to become pressurized (i.e., no freeboard) during the 500-year event.

7.1 Climate Resilience Tools

WSDOT also evaluates crossings using the mean percent change in 100-year flood flows from the WDFW Future Projections for Climate-Adapted Culvert Design program (Appendix I). All sites consider the 2080 percent increase throughout the design of the structure.

7.2 Hydrology

For each design WSDOT uses the best available science for assessing site hydrology. The predicted flows are analyzed in the hydraulic model and compared to field and survey indicators, maintenance history, and any other available information. Hydraulic engineering judgment is used to compare model results to system characteristics; if there is significant variation, then the hydrology is reevaluated to determine whether adjustments need to be made, including adding standard error to the regression equation, basin changes in size or use, etc.

In addition to using the best available science for current site hydrology, WSDOT is evaluating the structure at the 2080 predicted 100-year flow event to check for climate resilience. The design flow for the crossing is 58 cfs at the 100-year storm event. The projected increase for the 2080 flow rate is 9 percent, yielding a projected 2080 flow rate of 63 cfs. The design flow for the West Fork Hoquiam is 428

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cfs at the 100-year storm event. The projected increase for the 2080 flows at the crossing were also applied to the West Fork Hoquiam River yielding a projected 2080 flow rate of 467 cfs.

7.3 Climate Resilience Summary

A minimum hydraulic opening of 13 feet and a minimum maintenance requirement clearance of 6 feet from the channel thalweg to the inside top of structure allows for extreme event flows to pass through the replacement structure safely under the projected 2080 100-year flow event. This will help to ensure that the structure is resilient to climate change and the system is allowed to function naturally, including the passage of sediment, debris, and water in the future.

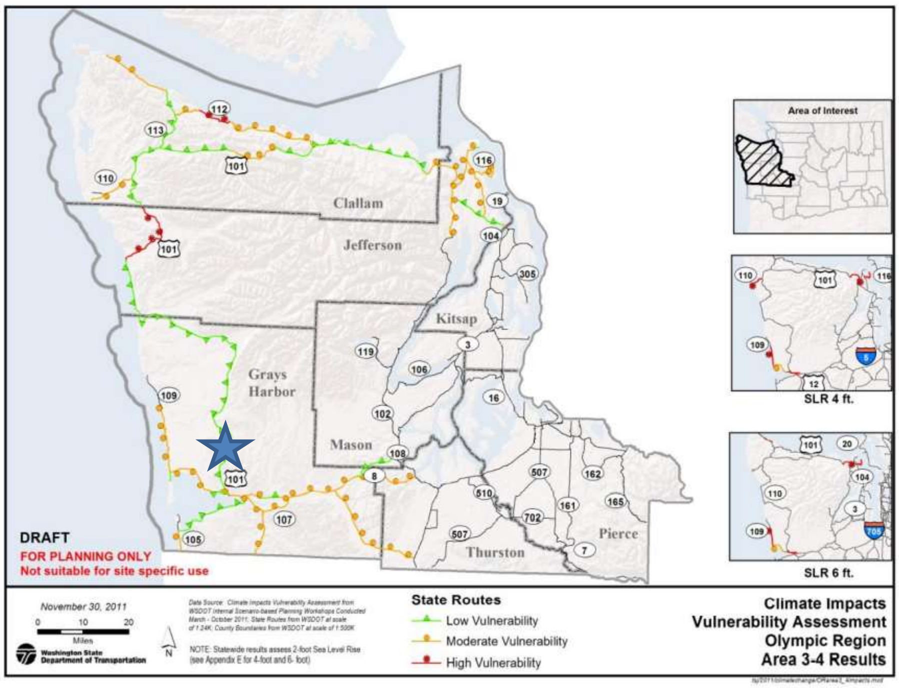

Figure 67: Climate impacts vulnerability assessment of Olympic Region areas 3 and 4 (source: WSDOT 2011). Site location is indicated by star

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8 Scour Analysis

Total scour will be computed during later phases of the project using the 100-year, 500-year, and projected 2080 100-year flow events. The structure will be designed to account for the potential scour at the projected 2080 100-year flow events. For this phase of the project, the risk for lateral migration and potential for degradation are evaluated on a conceptual level. This information is considered preliminary and is not to be taken as a final recommendation in either case.

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8.1 Lateral Migration

Based on the evaluation in section 2.8.5, the risk for lateral migration of the project stream is considered negligible. However, given the crossing is located just upstream of the confluence with the West Fork Hoquiam River, there is some risk to the crossing and roadway from lateral migration of the mainstem channel. The risk is considered generally low based on the apparent stability of the mainstem planform in the vicinity of the confluence. Nonetheless, to counter potential channel migration and resulting lowering of the project stream grade downstream of the culvert, the design includes installation of embedded LWM along the left bank of the project stream below the culvert, in anticipation of future meander migration of the mainstem.

8.2 Long-term Aggradation/Degradation of the Riverbed

Based on the evaluation in section 2.8.4, there is a little risk of long-term aggradation at the project site over the life of the replacement structure. There is some risk of degradation if grade controls in the West Fork Hoquiam River decompose or wash out, where the 1.8 percent gradient in the long profile upstream extends downstream. The maximum degradation in that scenario would be less than 2 feet at the downstream end and 0.5 feet at the upstream end of the replacement culvert.

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8.3 Local Scour

Three types of scour will be evaluated at this site: bend scour upstream near the inlet, inlet scour, and contraction scour. Initial scoping level calculations indicate the amount of local scour will likely be small, on the order of 1 feet. These forms of scour will be evaluated in greater depth after the stream channel design has been finalized. Large wood pieces placed in the channel will have pre-formed scour holes constructed prior to rootwad placement.

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Summary

Table 18 presents a summary of this PHD Report results.

Table 18: Report summary

Stream crossing category	Elements	Values	Report location
Habitat gain	Total length	3,401'	2.4 Site Description
Bankfull width	Average BFW	9.0'	2.8.2 Channel Geometry
	Reference reach found?	Y	2.8.1 Reference Reach Selection
Channel slope/gradient	Existing crossing	1.7%	2.8.4 Vertical Channel Stability
	Reference reach	1.9%	2.8.1 Reference Reach Selection
	Proposed	1.5%	4.4.2 Channel Planform and Shape
Countersink	Proposed	FHD	4.7.3 Freeboard
	Added for climate resilience	FHD	4.7.3 Freeboard
Scour	Analysis	FHD	8 Scour Analysis
	Streambank protection/stabilization	FHD	8 Scour Analysis
Channel geometry	Existing	-	4.4.2 Channel Planform and Shape
	Proposed	Realign	4.4.2 Channel Planform and Shape
Floodplain continuity	FEMA mapped floodplain	N	6 Floodplain Changes
	Lateral migration	Low	2.8.5 Channel Migration
	Floodplain changes?	Y	6 Floodplain Changes
Freeboard	Proposed	2.0’	4.7.3 Freeboard
	Added for climate resilience	Incorporated	4.7.3 Freeboard
	Additional recommended	1.0'	4.7.3 Freeboard
Maintenance clearance	Proposed	6.0'	4.7.3 Freeboard
Substrate	Existing	D_{50}=1.0”	2.8.3 Sediment
	Proposed	D_{50}=0.8”	5.1 Bed Material
Hydraulic opening	Proposed	13.0'	4.7.2 Minimum Hydraulic Opening Width and Length
	Added for climate resilience	N	4.7.2 Minimum Hydraulic Opening Width and Length
Channel complexity	LWM	Y	5.2 Channel Complexity
	Meander bars	Y	4.4.2 Channel Planform and Shape
	Boulder clusters	MAYBE	4.4.2 Channel Planform and Shape

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	Mobile wood	N	5.2 Channel Complexity
Crossing length	Existing	80’	2.7.2 Existing Conditions
	Proposed	53’	4.7.2 Minimum Hydraulic Opening Width and Length
Floodplain utilization ratio	Flood-prone width	26.5'	4.2 Existing-Conditions Model Results
	Average FUR upstream and downstream	2.9	4.2 Existing-Conditions Model Results
Hydrology/design flows	Existing	Regress	3 Hydrology and Peak Flow Estimates
	Climate resilience	Yes	3 Hydrology and Peak Flow Estimates
Channel morphology	Existing	Stage 1	2.8.5 Channel Migration
	Proposed	Stage 1	5.2 Channel Complexity
Channel degradation	Potential?	Low	8.2 Long-term Aggradation/Degradation of the Riverbed
	Allowed?	Y	8.2 Long-term Aggradation/Degradation of the Riverbed
Structure type	Recommendation	N	4.7.1 Structure Type
	Type	NA	4.7.1 Structure Type

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Appendices

Appendix A: FEMA Floodplain Map

Appendix B: Hydraulic Field Report Form

Appendix C: SRH-2D Model Results

Appendix D: Streambed Material Sizing Calculations

Appendix E: Stream Plan Sheets, Profile, Details

Appendix F: Scour Calculations (to come in FHD)

Appendix G: Manning's Calculations

Appendix H: Large Woody Material Calculations

Appendix I: Future Projections for Climate-Adapted Culvert Design

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